26

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October 25, 1989
(Via Airborne Express)

Mr. John P. Schiffer
Physics Letters B
Editor of Experimental Intermediate-
Energy and Heavy-Ion Nuclear Physics
Physics Division - 203
Argonne National Laboratory
Argonne, IL 60439-4843

RLG Copy

Dear John,

Enclosed is the package of materials I just received by Airborne Express from P.K. Iyengar.

I am sending this also by Airborne Express to Jake Bigeleisen, Darleane Hoffman, and Bill Woodard.

I have two other items of interest. I have just talked with Gerd Friedlander, who I gather is going to talk to the Cold Fusion Panel Monday (where I will not be). They now see clearly He3, and find it roughly equal to the T output in their experiments. Certainly, according to Friedlander, it is at least 80 percent of the T yield. As a matter of general interest, the acceleration of clusters of light water gives a yield about 5 percent that obtained with heavy water clusters (both against a deuterated polyethylene target). Interestingly, with heavy water clusters against a normal polyethylene target, they see less than one percent of the yield obtained with deuterated polyethylene target.

I have spoken with Mike Miller, of Menlove's group at LANL. Over the last 6 weeks, about as many runs with hydrogen as with deuterium; no bursts with hydrogen, and more deuterium runs give nothing than give bursts. Still no separation of counters.

Finally, I have a letter from from Etienne Roth, who says that absolutely no positive results have been observed in France.

I am now puzzling over Iyengar's papers.

Sincerely yours,

Richard L. Garwin

Encl:
10/19/89 LTR P.K. Iyengar to RLG (including attachments). (101989.PKI)

cc:
> J. Bigeleisen, Stony Brook (Via Airborne Express).
> D.C. Hoffman, Berkeley (Via Airborne Express).
> W.L. Woodard, ERAB (Via Airborne Express).

RLG:jah:298%JPS:102589.JPS

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GOVERNMENT OF INDIA
भाभा परमाणु अनुसंधान केन्द्र
BHABHA ATOMIC RESEARCH CENTRE

Dr. P. K. Iyengar
Director

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बम्बई-४०० ०८५, भारत.
TROMBAY,
BOMBAY 400 085,
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TLX : 011-71017-IN
GRAM : BARC-CHEMBUR

Ref:DIR- 468 -89 October 19, 1989

Dear Dr. Garwin:

Thank you for your letter of October 16th. As requested I am sending you a copy of the paper B-3, which will be in our compilation.

During my visit to U.S.A. I had occasion to discuss cold fusion with a number of people especially those at A&M University, College Station, Texas, Texas University at Austin and Brookhaven National Laboratory. I am pretty sure now that there is good confirmation of our results from the experiments done at A&M Texas. The work done at BNL using cluster beam also indicates tritium channel dominant compared to the neutron channel. I do not particularly think the explanation on the basis of impact fusion is strictly correct. The clusters probably disintegrate and provide~~d~~ deuterons of energy from a few electron volts to a few KeV. It is not surprising that the results have shown only tritons and protons.

You are also probably aware of a Russion paper on the high isotope ratio 3Helium/4Helium in technical grade metals, published in 1978. It is surprising that they make this statement "It can be assumed that 3He in metals is formed as the result of processes which occur right in the metal and these processes lead to the formation of either -3He, T, or T and -3He together. An analog of processes of this type is the nuclear reation which takes place with the interaction of deuterium mesic atoms with ordinary deuterium atoms at thermal energies μ-d + d -- 3He + n + μ-." It looks as if cold fusion was invented **as early as in 1978!**

The question of reproducibility has engaged the attention of many. I am afraid most of the chemists deal with very small electrodes which is one of the reasons for their poor success. I feel if large surface and large volume electrolytic cells are used, the success rate is higher because conditions necessary for cold fusion reaction either at the surface or in the volume is more likely to be achieved. What these conditions are, I do not venture to predict, but perhaps will be revealed by many experiments being done at present.

We have looked at some of the deuterated titanium targets obtained for low energy nuclear physics experiments from Amersham a long time ago. Presently they show auto-radiographs from tritium formed on the target, similar to the one described in my paper. We have also verified this by detecting titanium x-rays

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by using silicon detector. The calculation on the basis of radioactivity seen at present and assuming a constant rate of DD cold fusion, the figure of 10^{-12} per DD pair per second is obtained. This checks with the figure that one obtains in the electrolytic cell. I am sure this could be checked since several of these targets must be available in the laboratories. The amount of tritium activity is such that it could not have been present at the time of loading with deuterium gas.

It seems to me certain that there is no way of escaping the fact that DD cold fusion does occur in metallic lattices. It is like discovering that neutron induced fission takes place in uranium. It took a long time before appropriate conditions were invented to make it a source of energy. Perhaps it will take some time before we can obtain appropriate conditions in the metal lattices, or perhaps using external agents by which energy production along with tritium will be feasible. There is definitely a hope.

"Science Marches On".

With best wishes,

Yours sincerely,

(P.K. Iyengar)

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AUTORADIOGRAPHY OF DEUTERATED TARGETS FOR SPATIALLY RESOLVED DETECTION OF TRITIUM PRODUCED BY COLD FUSION

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INTRODUCTION

For the last few months, hectic activity is underway in various laboratories to study the Cold Fusion phenomenon. De Nino et al [1] reported emission of neutron from titanium metal loaded with deuterium gas under pressure. Similar experiments have been conducted at Trombay. We report here evidence of cold fusion in D_2 gas loaded Ti and Pd targets through the use of autoradiography for spatially resolved detection of tritium. Our study employed three different techniques to observe tritium :

(i) Autoradiography using X–ray films.
(ii) Characteristic X–ray measurement of titanium, excited by the tritium β.
(iii) Liquid scintillation method for tritium β counting.

LOADING OF DEUTERIUM

Titanium and palladium metal samples of various shapes and sizes were loaded with deuterium by two different ways. In the first method [2] individual titanium target was heated by R F heating up to a maximum temperature of $\simeq 900^\circ$ C in vacuum and then in deuterium gas atmosphere to absorb deuterium. In the second method [3] the foils of palladium (Pd–Ag alloy) were heated (by ohmic heating) up to a temperature of 600° C in vacuum (10^{-5}mm of Hg) and then in D_2 gas. The deuterium gas used for loading had a tritium content of $\lesssim 3$ Bq/cc.

AUTORADIOGRAPHY

Autoradiography is a simple and elegant technique of detecting the presence of radiation emitting zones. This technique has the advantage of being free from any electromagnetic interference (pick ups, discharge pulses etc), has relatively high sensitivity as it can integrate over long exposure times and can give very useful information in the form of space resolved images. In order to achieve good resolution of the image, the sample was kept very close to the X–ray film. Standard medical X–ray film of medium grain size (10 to 15 μm in diameter) on cellulose triacetate base was used for this purpose. The exposure time used for the deuterated samples varied from 18 hours to a few days. At times a stack of several films was used. In some cases films were placed on both sides of the sample. For latent image formation we used IPC (India Photographic Company Ltd.) made 19B developer and IPC made fixer. The developing time was typically 4 to 5 minutes. Out of many samples which had absorbed D_2 gas, only a few showed latent image of the object. The obtained results are tabulated in Table–I.

The radiographs (Fig.1) of deuterated titanium disc target showed several spots randomly distributed within the sample boundary. The occurrence of spots all along the rim of the mechined targets is very intriguing. The X–ray image (Fig.2) of a conical target showed periphery of the cone. Repeated measurements over a period of one month, with same sample with varying exposure time gave almost identical pattern and intensity distribution of spots, indicating that the radiation emitting regions were well entrenched in the face of the titanium lattice. The fact that the second film of a stack of films exposed to the target also indicates similar though less intense spots, rules out the possibility of any kind of chemical reduction reaction caused by the deuterium or hydrogen in the target being responsible for causing the spots.

The latent image (Fig.3) of Pd–Ag foils however exhibited a different kind of behaviour. The images though indicated variation in intensity and some spots but on the whole the fogging was more uniform. Unlike deuterated titanium targets, the intensity of fogging reduced very rapidly i.e. within a couple of days the activity reduced below measurement level.

MEASUREMENTS OF X–RAY EMISSION

The characteristic X–rays emitted from the deuterated metals (Ti and Pd) were studied with the help of a Si – Li (Silicon – Lithium drifted) detector by the Nuclear Physics Division. The detector had a beryllium window of 75 μm thickness. The X–rays of Ti ($K\alpha$ = 4.5 Kev, $K\beta$= 4.9 Kev) were observed in case of conical (Fig.4) and disc (Fig.5) sample. The intensity of conical sample was much more than that of disc sample. The deuterated Pd–Ag foils indicated the X–ray peaks (Fig.6) corresponding to titanium presumably because of a small amount of titanium impurity picked up by the foils from the D_2 loading chamber which had earlier been used for loading of Ti samples. We did not observe the L X–rays of palladium or silver.

LIQUID SCINTILLATION COUNTING

This was carried out at the Health Physics Division using the facilities described in Ref.(4). The sample was simply dropped into a vial containing liquid scintillator cocktail and the tritium activity was counted by two photomultiplier tubes in coincidence. The typical activities were 50 to 1000 Bq as compared to a background of less than 0.2 Bq. No correction was applied for possible quenching/shadowing effects.

RESULTS AND DISCUSSION

The fogging observed in autoradiographs (Fig 1,2 & 3) is the combined effect of tritium and characteristic X–rays of the host material. The radiograph of the disc sample (Fig.1) indicates evidence of tritium localised in the form of micro structures. These spots are unevenly distributed on the face of the titanium, there are about 60 to 70 spots in all. On correlation with the X–ray counts under the peak (K X–ray peak) and liquid scintillation counting result it was found that the each emitting spot corresponds to 10^8 to 10^9 atoms of tritium, In comparison the total number of deuterium atoms loaded in the disc sample was $10^{19}$to 10^{20}. The X–ray images (Fig.3) in case of Pd–Ag foils were uniformly fogged and intensity of fogging was reduced very rapidly with time unlike ~~tritium~~ titanium. This type of change in pattern was attributed to the high mobility of tritium in palladium as compared to that in titanium. Observation of K X–ray peaks of titanium (Fig.4, 5 & 6) by Si–Li detector was the result of excitation of K–shell by tritium or tritium β. L X–ray of palladium or silver was not observed because of low fluorescent yield for L X–ray and the detector window (75 μm) was too thick to allow observable quantity of L X–rays. Liquid scintillation counting further confirms the presence of tritium in the samples. It may also be pointed out that the tritium observed even on the surface of the samples exceeded the total quantity of tritium contained in the deuterium gas used to load the samples, therefore, the gaseous tritium, even if preferentially absorbed by the samples can not explain this phenomena. Undeuterated metallic targets machined out of same titanium rods did not indicate any detectable tritium signal.

SUMMARY AND CONCLUSION

(i) Our experiments based on the titanium, obtained from Misra Dhatu Nigam, India and palladium from Mathley Johnson, U.K. Only a few samples showed cold fusion out of a number of tested samples. The cold fusion may be very rare and random phenomena and occurs in selected samples. This perhaps is the reason for controversy regarding the existence of cold fusion.

(ii) The autoradiographs show the fusion sites in the sample. The fusion may have taken place during the loading of sample. Though we fail to locate new sites after first imaging, the fusion phenomena even after loading period can not be ruled out. The fusion may be taking place at the same regions or at any other region with low activity not enough for detection.

(iii) The neutron measurements [5] have not given any positive result of neutron production during or after loading of deuterium. This is quite surprising since in the case of usual D–D fusion reaction producing tritium or neutron, has almost equal cross–section for both the channels. Even if the neutron production is inhibited due to some unknown reasons, the tritium produced at 750 Kev, reacting with surrounding deuterium, is capable of generating fusion neutrons by the reaction

$$D + T \longrightarrow {}^4He + n \ (14 \ MeV)$$

The neutrons produced by above process will be 10^{-4} times the tritium atoms generated. Our detectors were sensitive enough to detect these neutrons if produced. Similar results have also been obtained from our electrolysis based cold fusion experiments [6].

(iv) It was observed that ~~the~~ there was no correlation between the the amount of gas loaded and the tritium activity of the samples. Some samples of Pd black, Ti sponge and zirconium powder absorbed very high amount of deuterium but failed to show any cold fusion. In our experiments all the samples that exhibited cold fusion were loaded with deuterium much below the quantity required for phase change.

(v) The samples exhibiting cold fusion seem to have some kind of aging effect. Samples which had shown cold fusion (i.e. autoradiograph) in the first loading also generated tritium in the second deuteration. But failed to show any evidence of cold fusion in the subsequent deuterations.

Acknowledgements

Authors sincerely wish to express their gratefulness to Dr. P K Iyengar, Director, BARC for his keen interest and constant guidance in the present work. We are also thankful to M S Krishnan, S Malhotra, S Shrikhande and K C Mittal for deuteriding the targets. We also grateful to V S Ramamurthy and Madan Lal for the measurement of characteristic X–rays. T S Iyengar has carried out tritium measurements described in this paper the authors would like to express their thanks to him.

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[6] Krishnan M S et al, 1989, ibid A1.

FIGURES

Fig. 1 Autoradiograph of deuterated Ti disc sample
Fig. 2 Autoradiograph of deuterated Ti conical sample
Fig. 3 Autoradiograph of Pd–Ag foil
Fig. 4 Si–Li detector signal of Ti disc target
Fig. 5 Si–Li detector signal of Ti conical target
Fig. 6 Si–Li detector signal of Pd–Ag foil

Table. I

Sample Identification No.	CS003	DS001	PS001
Figure No.	2	1	3
Material	Ti	Ti	Pd–Ag
Shape of Sample	cone	disc	Foils
Sample Mass (mg)	187	998	110
D_2 Absorbed (mg) D_2 Loading process	0.07 Ref.2	0.42 Ref.2	0.73 Ref.3
Date of D_2 Loading	9–6–89	14–6–89	22–8–89
Date of Exposure	14–6–89	23–6–89	24–8–89
Exposure Duration	24 Hr	66 Hr	88 Hr
Si–Li Result (10^5 Bq) Date of Measurement	1.3 16–6–89	0.29 16–6–89	2.96 24–8–89
Liq–Scin. Result (Bq) Date of Measurement	850 15–6	28 26–6	xx xx
Repeatition Rate for Autoradiography	3	9	4

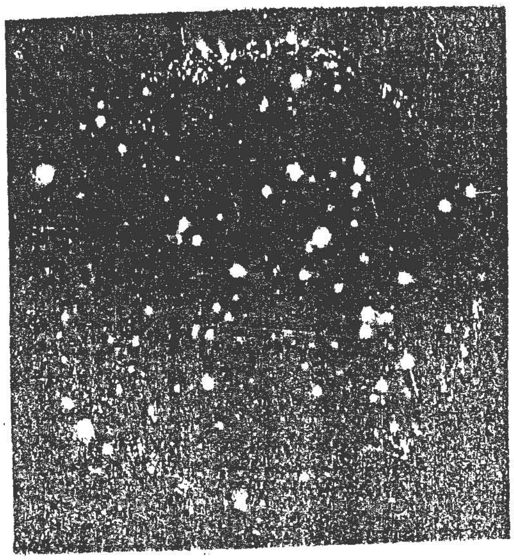

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Fig.1

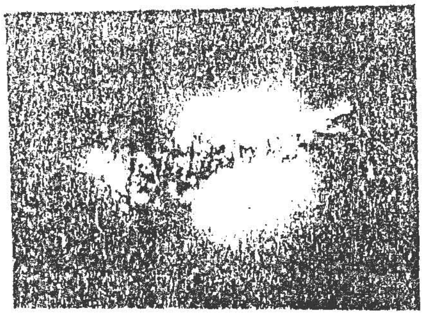

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Fig.2

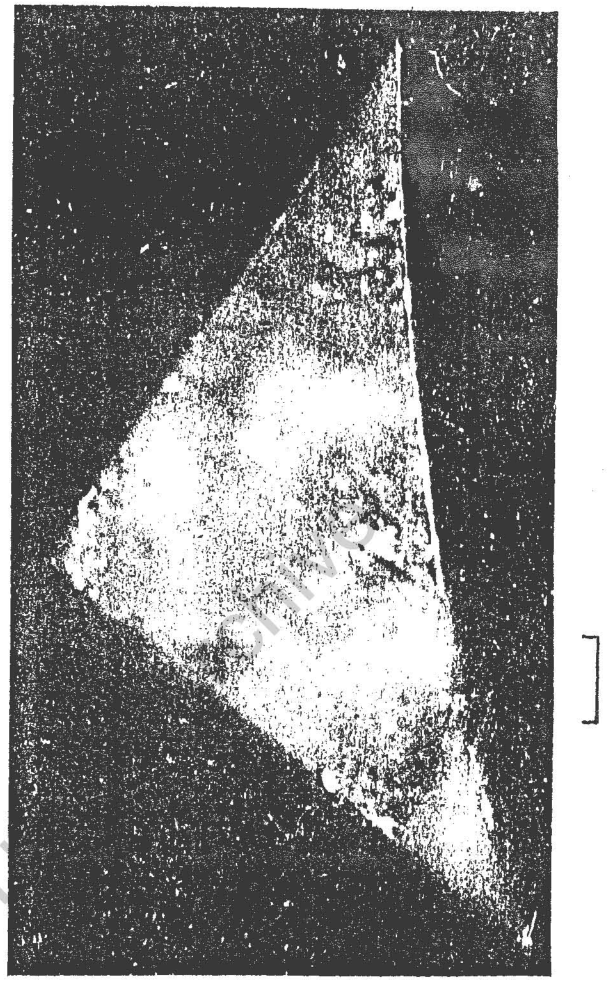

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Fig. 3

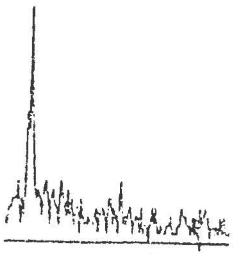

Fig.4

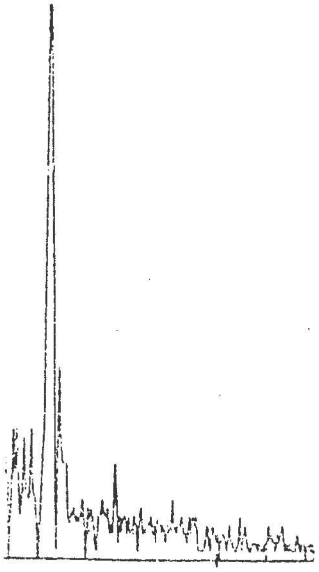

Fig.5

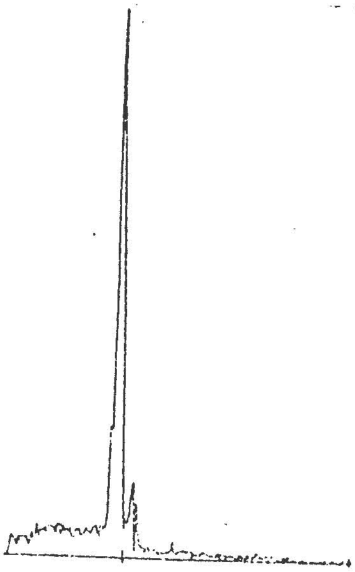

Fig.6

COLD FUSION

P.K. Iyengar

Energy production in the universe is mostly based on nuclear reactions especially fusion reactions of light elements. Energy production in the sun on the basis of fusion of hydrogen, its isotopes and elements upto carbon have been theorized. It is quite natural to expect that there will be a large variety of nuclear reactions which will lead to the production of nuclear energy. This would depend upon the mass of the object, the temperature and other forces which can contribute to density changes and changes in the potential barrier for interaction between nuclei. In fact even before the discovery of the neutrons, scientists had predicted and even tried to prove that nuclear energy could be produced by fusion of hydrogen atoms. It was only after detailed accelerator based research in nuclear physics, that the cross-sections and Q values were available. This enabled many conjectures to be made. In fact there is a whole area of fusion reactions in astrophysics in which one can imagine various types of nuclear interactions and modes of decay for energy production. The collapse of the binary stars and neutron stars turning to black holes are the ultimate phases of the production of fusion energy. It is, therefore, very interesting to renew our acquaintance with yet another new methoding of fusion energy production in the context of the prediction of cold fusion.

There is a set of nuclear reactions involving hydrogen isotopes which can lead to production of energy, as well as continuing the chain reactions in special circumstances. These

Tokamaks has been the major success. It has almost reached the stage of breakeven in energy production. However, the large size and the expensive equipment needed to attain even this breakeven stage has led to doubts about its commercial viability. Small and more elegant methods have been developed. The plasma focus, exploding wire and shock wave compression are all techniques which are under experimentation with the sole aim of producing neutrons from the fusion reactions. It is interesting to note that in this process considerable innovations and cross fertilization of new ideas have taken place in the last couple of decades. Therefore, any addition to these new ideas is welcome and must be tried out. What we are going to discuss today is an innovation which on the face of it looks so simple that it seems too good to be true. It has also generated considerable speculations on the process which cause fusion in the solid state at low temperatures. The basic problem is essentially to bring together ions of hydrogen isotopes at distances of few Fermis so that fusion takes place. In this connection it is worth recalling the attempts to bring together hydrogen nuclei to a distance at which the spontaneous fusioning rate would increase considerably. The most effective method has been the replacement of the orbital electron by a μ mason. Because of its heavier mass, it is able to squeeze the nuclei in a molecule and increase the probability of fusion. It also has an additional advantage. Because of its longer life time, freed after the reaction it can catalyze more fusions. Almost 200 catalyzed fusions per μ mason have been observed. It is the same scientists who were concerned with μ mason catalyzed fusion that have also reported cold fusion in a essentially dictated by quantum mechanics is very debatable.

I would like to invite your attention to one of the unaccepted involvement of the theory of quantum mechanics to such a problem. Several years ago Rand McNally had invented the basic phenomenon of cold fusion and in fact he had named it in 1983 to quote in his own words "The problem of neutron transfer in solid media is no longer an elementary binary collision process involving Coulomb barriers and brief collision times but rather one in which the nuclei are continuously in each others proximity. Since the ^{135}Xe has a slow neutron capture radius approaching that of the inter atomic distance the nuclear barrier would perhaps be grossly reduced. Thus it is remotely possible that some combination of natural processes may permit barrier penetration to occur much more readily and a nuclear reaction to ensue". He also invented the term called de Broglie interaction length which is based on the fact that the de Broglie wave length of particles with small kinetic energy are in fact very long. In fact it is this property that provides an extraordinarily high cross section for absorption of slow neutrons by certain nuclei. It is in this connection that one must know what the de Broglie interaction length and effect of the extension of the de Broglie waves will be in the case of a hydrogen atom with very small energies in a palladium lattice. What would happen to the charge distribution of such a deuteron and its effect like polarisation are too speculative. Perhaps if the charged distribution has dimensions of the order of de Broglie interaction length, then the potential barrier due to Coulomb interaction could be made

University group and the invention by Fermi, the physics of heterogeneous multiplying system, the nuclear reactor would not have been invented. Similarly one has to explore and understand the basic mechanisms of fusion in a lattice and find out how this could be used either to produce energy directly or to produce neutrons and tritium or both in a sustained manner. It is too early to make time targets but when one is familiar with the nuclear technology one could foresee how it will change our efforts in many areas. "A world of copious neutrons" was the topic of a conference in 1982. The fast reactor essentially uses the reactor as a source of extra neutrons, so does the fission fusion hybrid. It is therefore quite conceivable that cold fusion may turn out to be yet another source of neutrons for applications.

It has been conjectured that there are other channels by which the fusion reactors can produce energy with almost little or no radioactivity. This is a very interesting concept which can be used effectively to produce fusion energy in small devices. Availability of neutrons for isotope production is yet another area for applications. Neutron therapy & neutron radiography, both can be done with portable neutron source to great advantage. Above all the source of such energy and neutrons depends only on the sea water which is available in plenty and the technology to separate and concentrate deuterium from water is well known.

I would therefore end this introduction by quoting from what Dr. Bhabha said at the first International Conference in

…ate the procedure of obtaining the best equation of state on the basis of a system of equivalent equations and to estimate the degree of reliability of calculation of any thermodynamic function from experimental p, v, T data but also to ascertain the advisability of incorporating one group of data or other into the calculations and thus to optimally plan further experiments.

---

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Translated by Eugene Lepa

Anomalously high isotope ratio $^3He/^4He$ in technical-grade metals and semiconductors

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(Presented by Academician V. M. Tuchkevich, February 24, 1978)
(Submitted February 16, 1978)
Dokl. Akad. Nauk SSSR, 241, 1054–1057 (August 1978)

PACS numbers: 82.90.+j, 35.10.Bg

The helium isotope ratio in any object carries information about processes leading to their formation.

Table I lists natural objects containing helium with sharply differing isotope ratios and also indicates the main processes leading to the formation of helium with the corresponding isotope ratios.

It is shown in the present paper that in a number of commercially-pure metals and semiconducting materials helium is found to be present in a $^3He/^4He$ ratio of close to 1, i.e., several orders of magnitude higher than the values given in Table I. This would indicate that the origin of helium isotopes in the materials studied was due to some processes, nuclear or physicochemical, other than those enumerated in Table I. A high $^3He/^4He$ ratio in aluminum was reported by Alimova et al.[9]

I. It turned out that our investigations, as those in Ref. 9, could be carried out by employing a sensitive mass-spectrometric technique[10] and a low-background gas-liberating apparatus.[11]

The gas was extracted from the samples by heating them in a vacuum unit with a corundum crucible. The helium was then purified by removing the accompanying gases with liquid-nitrogen-cooled carbon traps and a titanium getter heated to T ~ 400°C, after which the helium isotopes were analyzed in a magnetic resonance mass spectrometer. The minimum measureable quantities of ^3He and ^4He were $\sim 10^6$ and 10^9 atoms, respectively.

We studied samples of 18 elements from all groups of the Mendeleev periodic system (Ni, Cu, Al, Ti, Au, Mo, Ta, Ag, Zn, Pb, Bi, Pd, Pt, Re, Ir, Ge, Si, and InSb). Three to five samples of each element were studied; more thorough investigations were made of Ni (~200 samples), Cu (~30), Ta (~20), Ti (~20), Au (10), and Al (40). In most cases the samples were foil ribbons measuring (0.05–0.1) × 10 × 125 mm. The impurities in the samples corresponded to the standard commercially-pure metals.

II. The results of the investigations, based on analysis of more than 300 samples, reduce to the following. Many

TABLE I

Object	Processes	$^3He/^4He$	Source
Earth's crust	α-decay of radioactive elements, reactions of type $^6Li(n, \alpha)T$, $T \xrightarrow{\beta^-} {}^3He$	10^{-7}–10^{-8}	(1)
Uranium-thorium minerals	Ditto	10^{-9}–10^{-10}	(2)
Lithium-beryllium minerals	" "	10^{-5}–10^{-7}	(3)
Upper mantle of Earth	Ditto, presence of primary helium captured during formation of Earth	$3\cdot10^{-5}$	(4, 5)
Atmosphere	Diffusion of helium isotopes from mantle to crust, dissipation of helium isotopes into outer space, nuclear reactions in upper atmosphere with formation of T, ^3He	$1.4\cdot10^{-6}$	(6, 7)
Lunar soil	Spallation reactions, implantation of solar wind	$3\cdot10^{-4}$	(8)

0038-5689/78/08 0581-03 $01.40

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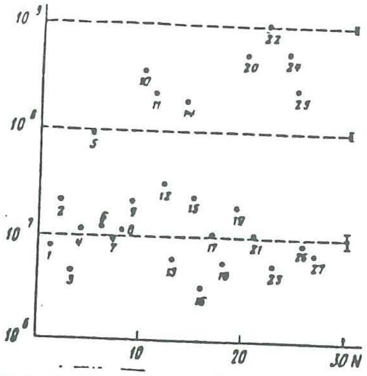

FIG. 1. Distribution of ^{3}He in segment of nickel foil; n is the number of atoms in a sample measuring 0.05 • 10 • 125 mm, N is the ordinal number of the sample. The vertical segments characterize the error of measurement.

samples contain a considerable quantity of ^{3}He. These quantities vary markedly both from element to element (10^{10}–10^7 atoms/g) and from sample to sample (from 10^{10} atoms/g to a background value of $\sim 10^6$ atoms/g).

The values of ^{3}He/^{4}He vary from 10^{-3} to 1. These values of the isotope ratio, are, apparently, underestimated since the quantity of ^{4}He, as a rule, should not exceed the threshold of instrument sensitivity (10^9 atoms) and in most cases this was the value taken for calculations.

The ^{3}He distribution was found to be spotty in character. In nickel foil (Fig. 1) samples with a comparatively high ^{3}He content are frequently next to samples with a comparatively low content. It may be said on the basis of the results that the spots in which ^{3}He is contained have a size of less than 1 mm. Next to a relatively large bunching of these spots is the practically complete absence of these spots along the length of the foil up to several tens of centimeters. The results of measurements of the ^{3}He content in other metals also indicate a pronounced nonuniformity in the ^{3}He distribution.

The curve of ^{3}He extraction from nickel foil (Fig. 2) displays two ^{3}He peaks much like those presented by Tishchenko et al.[12] who studied the desorption of helium from a silver film with various helium concentrations. Tishchenko et al[12] showed that when samples with high helium concentrations are heated the helium collects in microbubbles and is desorbed at ~1100°K. At low concentrations the desorption occurs by diffusion of individual atoms at a much lower temperature, 400–700°K. Comparison of our results with those with Ref. 12 shows that the desorbed peaks (Fig. 2) correspond to diffusion of individual atoms and, consequently, there were no bubble formations in our samples.

The certainty of the effect can be confirmed by the following facts.

1. The quantity of ^{3}He considerably exceeded the background level (100 times) in many samples.

2. Repeated (more than 50-fold) blank tests did not once yield quantities of ^{3}He which noticeably exceeded the background level of the instrument.

3. Two gas-liberating apparatuses of different construction were used to extract the gas and the picture of the effect was the same in both cases.

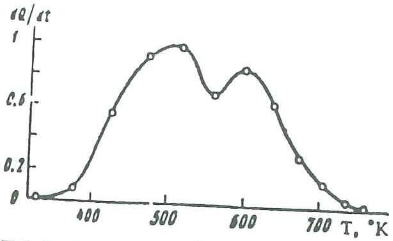

FIG. 2. Extraction of ^{3}He from nickel foil when temperature is raised uniformly at rate of 3.6 deg/min.

4. In some cases with the effect the sample was completely melted but in comparison with heating to 600°C (the ordinary procedure) this did not significantly change either the total quantity of ^{3}He extracted or the ^{3}He/^{4}He isotope ratio.

5. The quantity of ^{3}He in each sample was determine as the average of the heights of five recorded peaks whose magnitude practically did not change.

6. In our instrument[10] the ^{3}He line was completely separated from the HD and H_3 lines.

III. Let us consider the possible processes leading to the occurrence of ^{3}He in metals.

1. Diffusion from the ambient. Any processes of penetration from natural media cannot give the observed helium isotope ratio since there are no helium sources on Earth with such a high ^{3}He/^{4}He ratio. The possibility of the penetrating helium being enriched with the ^{3}He isotope by several orders of magnitude is apparently excluded because of the difference in the masses of ^{3}He and ^{4}He.

2. It may be assumed that ^{3}He in metals is formed as the result of the β-decay of tritium. Evidence in favor of the T-^{3}He bond is given by: the "point" character of the ^{3}He distribution which is much like the hydrogen distribution in metals[13]; some experimental data indicating the possibility of sharply increased concentrations of tritium in metal. The T/H ratio measured for several aluminum samples[14] was $\sim 10^{-9}$ which exceeds the ratio in possible ambient media by 6 to 8 orders of magnitude.[15] The usual processes of separation of isotopes by diffusion from the ambient medium evidently cannot yield the effects indicated (contamination of the samples with technogenetic T was ruled out).

3. There is a hypothesis[14] that the high tritium concentration in aluminum results from the separation of hydrogen isotopes in electrolysis during the production of the aluminum. However, the aluminum should be enriched in the process but this was not detected in the first experiments. Moreover, with this explanation metals produced without electrolysis should not have high T/H and ^{3}He/^{4}He ratios. However, many samples of metals obtained by the blast-furnace process, zone refining, as well as semiconductors obtained by the Czochralski method contain helium with a high ^{3}He/^{4}He ratio.

4. It can be assumed that ^{3}He in metals is formed as the result of processes which occur right in the metal and these processes lead to the formation of either ^{3}He, T, or T and ^{3}He together. An analog of processes of this type is the nuclear reaction which takes place with the interaction of deuterium mesic atoms with ordinary deuterium atoms at thermal energies $\mu^- d + d \rightarrow {}^3He + n + \mu^-$.

It should be borne in mind that the absolute concentration of ^{3}He and T in metals are low and the build-up time for ^{3}He and T may be quite long. Accordingly, even processes with a very low yield can, in principle, supply the observed quantities of ^{3}He in metals.

Reliable proof of the causes of the effect discovered requires further experiments.

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Translated by Eugene Lepa

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-R.L. GARWIN-
26 OCT 89 13. 13

Conclusions to Huizenga FAX

October 25, 1989

TO THE COLD FUSION PANEL

Enclosed is the draft report sections received to date, along with a copy of the agenda for our meeting.

The meeting will begin promptly at 8:30 a.m., but there will be coffee starting at 8:00. It will be in Room 4A-110 of the Forrestal Building.

One item which does not appear on the agenda is a briefing by the Naval Research Laboratory on their cold fusion research. They are not prepared to make their presentation during our open sessions, and therefore it is scheduled to take place during lunch on Monday.

Also enclosed for your information is a draft document prepared by H.O. Menlove, et al. of LANL.

Bill
William Woodard
Panel Secretary

AGENDA

COLD FUSION PANEL MEETING
OCTOBER 30-31
FORRESTAL BUILDING
ROOM 4A-110

Monday, October 30

8:30 a.m.	Discussion of Draft Report	J. Huizenga & N. Ramsey, Co-Chairmen
11:00	Cluster-ion Fusion Experiments at Brookhaven National Lab	G. Friedlander, BNL
12:00 noon	LUNCH	
1:00 p.m.	Discussion of Draft Report (continued)	
8:00p.m.	Adjourn	

Tuesday, October 31

8:30 a.m.	Discussion of Draft Report (continued)
12:00 noon	Adjourn

DRAFT
OCTOBER 30, 1989

DRAFT REPORT OF THE COLD FUSION PANEL OF THE ENERGY RESEARCH ADVISORY BOARD

This draft report has not been approved by either the Cold Fusion Panel or the Energy Research Advisory Board. It is the topic of discussion at the Panel's October 30-31 meeting and will not constitute the Panel's findings to the Board until after that date. Likewise, this draft in no way constitutes the position of the U.S. Department of Energy.

DRAFT

TABLE OF CONTENTS

Page

I. Executive Summary 1

II. Introduction 2

III. Calorimetry and Excess Heat 8

IV. Materials Characterization 17

V. Fusion Products ....

VI. Conclusions and Recommendations ....

Appendix A - Charge Letter

Appendix B - Panel Membership

Appendix C - Panel Meetings

EXECUTIVE SUMMARY

As a result of the startling announcements in March 1989 by Utah scientists claiming the attainment of cold fusion, the Secretary of Energy requested (see Appendix A) that the Energy Research Advisory Board (ERAB) convene a panel (see Appendix B) to assess the possibility of cold fusion. Since early May 1989, the Panel or subgroups thereof have participated in the Workshop on Cold Fusion in Santa Fe, have visited several laboratories, have studied the open literature and numerous privately distributed reports, and have participated in many discussions. The panel meetings and schedule of laboratory visits are summarized in Appendix C.

Since the above announcement, many laboratories worldwide have initiated research in cold fusion. In the United States, a major effort has been undertaken to search for cold fusion by a large number of research groups at industry, university, and national laboratories. Some laboratories support the Utah claims of excess heat production, usually for intermittent periods, but most report negative results. Even those claiming excess heat do not find commensurate quantities of fusion products, such as neutrons or tritium, that should be by far the most sensitive method to detect fusion. Neutrons near background levels have been reported in some D_2O electrolysis and pressurized D_2 gas experiments, but at levels 10^{12} below the amounts required to explain the experiments claiming excess heat. No one finds tritium levels commensurate with excess heat claims, though there have been a few reports of tritium above background levels.

The Panel finds that the experiments reported to date do not present convincing evidence that useful sources of energy will result from the phenomena attributed to cold fusion. Indeed, evidence for the discovery of a new nuclear process termed cold fusion is not persuasive. Hence, no special programs to establish cold fusion research centers or special programs to support new efforts to find cold fusion are justified at the present time.

However, there remain unresolved issues and scientifically interesting questions stemming from reported cold fusion efforts. Some of these are relevant to the mission of DOE and should be handled by carefully focused and cooperative efforts within current programs by normal mechanisms for project selection.

The reports of excess heat and fusion products are assessed in separate sections. Specific recommendations are summarized in the final section.

INTRODUCTION

The recent interest in cold fusion was stimulated by reports from Utah scientists in March 1989 that fusion had occurred in experiments on the electrolysis of heavy water (D_2O). Pons and Fleischmann at the University of Utah claimed to measure a production of heat that they could only explain by a nuclear process. Jones at Brigham Young University did not observe heat but did claim to observe neutron emissions that would also indicate a nuclear process. The claims were particularly astounding given the simplicity of the equipment, just a pair of electrodes connected to a battery and immersed in a jar of D_2O - equipment easily available in many laboratories.

This was not the first time fusion had been claimed to occur in electrolysis experiments, the earliest dating to the late 1920's in experiments that were later retracted, as discussed below. Nonetheless, the implications of the Utah claims if they were true and the ready availability of the required equipment led scientists around the world to attempt to repeat the experiments within hours of the announcement. These experiments are discussed in the following sections.

To understand the initial excitement, and also the profound skepticism, that has surrounded cold fusion experiments, it is helpful to review the nature of the fusion process.

The excitement stems mainly from the claims of heat production by nuclear fusion in these experiments. The attribution of heat production to fusion arises from the presence of deuterium, D, an isotope of hydrogen widely abundant in nature. The possible fusion reactions in deuterium are shown in Table 1. All of these nuclear reactions produce millions of times more energy per reaction than do chemical reactions. A simple way to harness this energy would be an important discovery.

Then, why the skepticism?

First, while a few researchers claim to confirm excess heat production, many report only negative results. The claims of excess heat are based upon rather difficult calorimetric measurements (see Section III). Many laboratories doing careful measurements do not find any heat production beyond that expected from normal water electrolysis, and the overall evidence in favor of excess heat production is not convincing.

The second reason for skepticism is the discrepancy between the claims of heat production and the failure to observe commensurate levels of fusion products, which should be by far the most sensitive method to detect fusion. Again referring to Table 1, we see that the only possible outcome of fusing two deuterium nuclei (each having 1 proton, 1 neutron) is the production of either tritium (T: 1 proton, 2 neutrons) or helium (2 protons, and either 1 neutron in He^3 or 2 neutrons in He^4). Moreover, the amount of heat produced and the amount of tritium or helium produced are strictly correlated. As is shown in Table 1, if 1 watt of heat production is observed (the maximum order of magnitude reported), then either tritium or helium must be produced at the same time at a rate of about 10^{12} atoms/second. In addition to tritium or helium, fusion in deuterium should also produce observable radiation in the form of a neutron, an energetic proton, or a gamma ray (see Table 1). These additional fusion products carry away most of the energy - millions of electron volts (Mev) of energy per particle. At such energies, the neutrons or gammas should easily escape and should be more readily observable than the heat. The proton should also be detectable directly or by its production of gamma rays.

The initial announcement by Pons and Fleischmann in March 1989 exhibited the discrepancy between heat and fusion products in sharp terms, as even some news accounts observed. Namely, the level of neutrons they claimed to observe was 10^9 times short of what was required if their alleged heat output were due to fusion.

The persistence of this major discrepancy in all subsequent experiments has led to various explanations as to how the observation of fusion products might be obscured. For example, some have suggested that in a solid the fusion energy is released directly as vibrations of the metal lattice, so that no hard radiations would be observed. In any case, this would not explain the absence of helium or tritium. Helium should be produced in about 50% of all reactions (see Table 1). Several electrodes from cold fusion experiments have been examined for helium, but at this writing, none has been observed. The amount of tritium directly observed in some experiments is much too small to account for observable heat. These data and their implications are discussed in Section IV.

A third reason for skepticism is that cold fusion should not be possible based on established theory. Nuclear fusion reactions have been studied for many years and their potential as a vast source of energy was well understood from the outset. It was also understood that net energy production from fusion should be possible at extremely high temperatures such as occur at the center of stars - millions of degrees centigrade. That fusion does occur under such conditions was firmly established with the successful development of thermonuclear weapons. As early as 1929, several years before fusion reactions were first observed in the laboratory, Atkinson and Houtermans proposed the now well accepted explanation that fusion is the source of energy from the sun.

The importance of high temperature arises as follows. For fusion to occur, two deuterium nuclei must come very close together (around 10^{-5} nanometers, 1 nanometer = 10^{-9}m). Because of their positive charge, nuclei repel each other, whereby they normally are separated by about 0.1 nanometer, much too far apart for fusion to occur. However, at very high temperatures, the atoms move with enough speed to overcome the mutual repulsion of their nuclei and therefore they do undergo close collisions. They approach more closely the higher the temperature until finally, at millions of degrees centigrade, fusion reactions begin to occur at a rapid rate. While it is possible to observe fusion reactions in the laboratory by accelerating deuterium nuclei to equivalent speeds in a particle accelerator, this cannot produce net power because the accelerated nuclei will preferentially slow down by colliding in cold matter rather than undergoing fusion. Thus, it has been thought that the way to create useful fusion energy is to recreate on earth the high temperatures found in stars. After decades of research, such temperatures - over 100 million degrees centigrade -have finally been achieved in the laboratory, but only in very large machines.

The idea that palladium or titanium might catalyze fusion stems from the special ability of these metals to absorb large quantities of hydrogen (or deuterium), the hope being that deuterium atoms would be close enough together to induce fusion at ordinary temperatures. The special ability of palladium to absorb hydrogen was recognized in the nineteenth century. In the late nineteen twenties, two German scientists, F. Paneth and K. Peters, reported the transformation of hydrogen into helium by spontaneous nuclear catalysis when hydrogen is absorbed by finely divided palladium at room temperature. These authors later acknowledged that the helium they measured was due to background from air. In 1927, Swedish scientist J. Tandberg claimed that he had fused hydrogen into helium in an electrolytic cell with palladium electrodes. On the basis of his work he applied for a Swedish patent for "a method to produce helium and useful reaction energy". After deuterium was discovered in 1932, Tandberg continued his experiments with D_2O. Due to Paneth and Peters' retraction, Tandberg's patent application was denied eventually [PAN].

In fact, even though palladium can store large amounts of deuterium, the deuterium atoms are still much too far apart for fusion to occur. Actually, deuterium atoms are closer together in D_2 gas molecules, which do not exhibit fusion. Palladium metal has a face-centered-cubic lattice with a cube edge of $\underline{a}=3.88 \times 10^{-1}$ nanometers. The deuterium atoms in palladium first occupy octahedral sites where the nearest deuterium-deuterium distance is 2.75×10^{-1} nanometers. One unit cell contains four palladium atoms and four deuterium atoms in octahedral sites. Any four nearest-neighbor palladium atoms form the vertices of a regular tetrahedron which serves as a tetrahedral site for a deuterium atom. The deuterium-deuterium distance between deuterons in the octahedral and tetrahedral sites is approximately 1.7×10^{-1} nanometers. These distances are large compared to the bond distance in D_2 gas molecules of 0.74×10^{-1} nanometers. Model calculations based on chemical forces indicate that at short distances the forces between deuterium atoms in palladium are more strongly repulsive than in free D_2 [MIN]. Other theoretical calculations are aimed at an investigation of the deuterium-deuterium distances of deuterium trapped by lattice defects in palladium. Again the distances between deuterium atoms in a Pd vacancy are predicated to be significantly larger than their interatomic distance in a D_2 molecule [BES]. To get around this, some have speculated that deuterium is not distributed uniformly on Pd lattice sites but somehow congregates locally, for example, at the surface. However, this is not supported either by direct observations or by theory.

[PAN] F. Paneth and K. Peters, Nature 118 455, 556 (1926); 119 706 (1927); also see Nature 339 May 18 (1989).

[MIN] J.W. Mintmire et al. Phys. Lett. 138A 51 (1989).

[BES] F. Besenbacher et al. preprint (1989).

The discrepancy between actual atomic spacings versus what is required for fusion to occur is not a small matter. As noted above, two deuterium nuclei must approach within 10^{-5} nanometers for fusion to occur. This requirement is mitigated by the quantum mechanical phenomenon of tunneling whereby nuclei at greater nominal separation may sometimes exist at very small separations, albeit very rarely. The small probability for doing so depends sensitively upon the details of the repulsive Couloub force due to their electric charge. For example, if it were possible to do so, compression of a deuterium molecule by a factor of 5 would enhance the fusion rate by about 40 orders of magnitude, while compression by a factor of 10 is required for an enhancement of 50 orders of magnitude. A 10-fold compression in separation distances is about what would be required to obtain a measurable fusion rate for palladium saturated with deuterium at a density roughly like that of the solid palladium. However, as ordinary experience shows, compressing solid matter 10-fold in length - a 1000-fold reduction in volume - would require enormous pressures. This, too, has finally been accomplished in the laboratory, but only for a tiny fraction of a second using the world's largest and most powerful laser beams. The effective "pressure" binding atoms in metals is orders of magnitude weaker (see Section IV).

These considerations apply both to the claims of excess heat and also to the more modest claims, first from Brigham Young University, that neutrons near background levels had been observed in D_2 electrolysis experiments, and later in pressurized D_2 gas experiments. These latter claims correspond to only 0.1 neutron per second, 10^{12} times less than would be needed to explain measurable heat. On the other hand, even such a slow rate of neutron production is at least 10^{40} times theoretical expectations and has therefore led to careful scrutiny of the validity of these claims, as discussed in Section V.

Again various speculations have been proposed to ascribe even this tiny level of neutron production to cold fusion, but none has yet been proved and some explanations have been eliminated one by one. To cite a few examples, the Brigham Young group initially suggested that fusion might result from collective electron effects in metals that cause electrons to appear heavy. This guess, later realized to be theoretically incorrect, was inspired by muon catalysis, itself sometimes called cold fusion. The muon, first discovered in cosmic rays in the 1940's, is an elementary particle with a mass 207 times that of an electron. In muon catalysis, the heavy, negatively-charged muon does act like a heavy electron in binding deuteron pairs at close enough spacing for fusion to occur. As presently understood, muon catalysis will not produce net energy in competition with the power required to produce the muons (too few reactions before the muon sticks to a helium nucleus made in the process), and providing a copious source of muons artificially created in accelerators is in any case a formidable challenge. Another speculative way to produce neutrons is electrical acceleration of deuterium ions when cracking causes a buildup of electrostatic charge in the crack. This has not been verified, nor would it lead to net energy production for the same reasons that laboratory accelerators do not, as noted above.

The calorimetric measurements of heat are discussed in Section III. Materials properties relevant to palladium and other metals used in cold fusion experiments are discussed in Section IV. The claims of observations of fusion products are discussed in Section V. Conclusions and recommendations are given in Section VI.

TABLE 1

LOW ENERGY FUSION REACTIONS OF HYDROGEN ISOTOPES

REACTION		ENERGY RELEASE (MeV)	REACTION/SEC PER 1 W OUTPUT
D + D →	$^{3}He+n$	3.27	1.90×10^{12}
D + D →	T + p	4.03	1.54×10^{12}
D + D →	$^{4}He + \gamma$	23.85	2.61×10^{11}
D + T →	$^{4}He + \gamma$	17.59	3.53×10^{11}
D + T →	$^{5}He + \gamma$	16.63	3.74×10^{11}
p + D →	$^{3}He + \gamma$	5.49	1.13×10^{12}
p + T →	$^{4}He + \gamma$	19.81	3.14×10^{11}

COLD FUSION PANEL REPORT

CALORIMETRY AND EXCESS HEAT

The claim for electrochemically charged palladium cells as prospective energy sources rests on reports by several groups of "excess heat" (or, more precisely, excess power) that cannot be accounted for in the thermal balance normally applied to water electrolysis. A number of other groups that have carried out careful calorimetric experiments in similar cells under a wide variety of conditions have found no excess heat. A summary of the published papers, and manuscripts submitted or in press available to the panel, are contained in Table 1. We also received a number of internal reports and private communications that were useful in assessing the question of excess heat. These varied widely with respect to number of trials, quality of data, number of control experiments, and types of cells and calorimeters. Many of these were considered by their contributors to be preliminary or interim reports, and in several, the results were ambiguous or inconclusive. These are listed in Table 2. Because it was difficult in most of these cases to examine the experimental procedures and results in detail, the quantitative results are not included in Table 2. The written reports from the national laboratories and others made available to the committee are on file. Among the issues the Panel addressed in examining published reports, assessing private communications, and in site visits were whether the power levels themselves are being accurately measured and whether the reactions being considered in these cells are, in fact, satisfying the chemical assumptions made. These heat measurements have been done with calorimetry that varied as to technique and to levels of precision and accuracy. In most cases calorimetric effects attributable to excess heat are small. The calorimetric measurements are difficult to make and may be subject to subtle errors arising from various experimental problems.

For the purposes of this report, the calorimetry is usefully differentiated as to whether the D_2 and O_2 gases are allowed to exit the cell completely unreacted (open cells) or are intentionally catalytically recombined to regenerate D_2O and to recover the corresponding heat (closed cells). In the case of open cells, where the gases are assumed to be vented without reaction, any output power (as heat) greater than the electrical input power minus the power equivalent of the D_2O formation enthalpy [1.527 V (volts) x I (cell current)] is considered excess, a result reported by several groups. In closed cells with total recombination (and with a deuterium-charged Pd electrode), the total electrical power in and total heat power out would normally balance (as for Pt and Pd electrodes in light water). At present, most experimenters who have performed calorimetry with closed cells under strict recombination conditions have reported no excess heat. Another important point is that most of the reported excess heat measurements are actually power measurements, and the data in most experiments have not conclusively demonstrated that the total amount of energy produced (as heat and chemical energy) integrated over the whole period of cell operation exceeds the total electrical energy input.

Since the claimed excess heats have, in most cases, been of a magnitude significantly less than the 1.527 V x I factor itself, issues of calibration, reliability, and support of the assumptions of zero recombination in open cells are especially critical. The Panel's site visits have identified experimental uncertainties, e.g., nonlinearities of the calibration in power output vs. temperature, time dependence of calibration, and doubtful accuracy of data acquisition relative to the magnitude of the effects asserted. (Appendix 2C) Even in laboratories that report excess heat, this effect, under apparently identical conditions, is not always reproducible. Moreover, in cases where groups reporting excess heat have supplied complete cells or materials to other laboratories, excess heat effects have not been confirmed. In none of our visits to the different sites did we see an operating cell that was claimed to be producing excess heat at that time. It is difficult to account for the widely divergent findings of excess heat. The failure to observe excess heat has been attributed to differences in materials (especially the Pd and D_2O), insufficient time of electrolysis and too small current densities, as well as to unknown effects of adventitious impurities or special, still unknown electrode surface conditions. However, examination of the results of those reporting positive effects (Table 1A) shows that a wide variety of Pd from different sources has been used. There is a similar variation in the number of sources and batches of D_2O. Current densities as low as 8 to 64 mA/cm^2 have been reported to produce excess heat, and much higher current densities than these have been used in cells yielding negative results (Table 1B). While very long electrolysis times have been required to produce excess heat effects in some laboratories, several have reported excess heat effects with electrodes of similar size that begin after a few hours of electrolysis. At this time we cannot find clear differences in materials, cells, or operating conditions that can account for the widely irreproducible behavior. After assessing the reports from the different laboratories, considering the experimental difficulties and calibration problems, as well as a lack of consistency and reproducibility in observation of the excess heat phenomenon, we do not feel that the steady production of excess heat has been convincingly demonstrated.

However, there are reports of sporadic temperature "excursions" or "bursts" that apparently represent power outputs signficantly larger than the input power. These events cannot be attributed to problems with accuracy or calibration alone and are presently not understood (see Appendix 2D).

Table 1. SUMMARY OF CALORIMETRIC RESULTS[a]

Published reports, manuscripts submitted or in press.

Research Group	Calorimeter[b] Cell	Pd type[c] source	Current Density, Voltage	Excess Heat	Controls[d]	Comments References
	A. GROUPS OBSERVING EXCESS HEAT					
1. Univ. of Utah Fleischmann, Pons et al.	ISO A open	JM rod, sheet, cube	8, 64, 512 mA/cm^2 3-10 V	5-111 % (9)	none	n, t, [FLE]
2. Texas A&M Univ. Appleby, Srinivasan et al.	ISO-HF (Tronac) open (s.s.)	Alfa wire	0.3, 0.6, 1.0 A/cm^2 3.4-5.6 V	6-30 %	H_2O Pt	[APP]
3. Stanford Univ. Huggins, Gür et al.	ISO A open	disks (arc melted)	10-1000 mA 3-15 V	10-30 %	H_2O	[BEL]
4. Texas A&M Univ. Bockris et al.	ISO A	H&S rods (Ni anode)	100-500 mA/cm^2	5-25 % (3 of 10)	Pt	[KAI]
5. U. Minnesota Oriani et al.	ISO-HF open	JM, ?[e] rod	0.6-1.6 A/cm^2	2-21% (2 of 3)	H_2O	[ORI]

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[a] Solutions were LiOD (usually 10.1 - 0.2 *M*) in D_2O. Anodes were generally Pt.

[b] See Appendix 2B

[c] JM, Johnson-Matthey; H&S, Hoover & Strong. The Pd was obtained from manufacturer in various forms (drawn, cast, cold-worked...) and subject to no further pretreatment, vacuum degassed, vacuum annealed, arc melted, preanodized, or recast, in both experiments finding excess heat and those yielding negative results.

[d] H_2O indicates substitution of H_2O for D_2O, and usually LiOH for LiOD in cell. Pt indicates substitution Pt for Pd.

[e] Electrolyte was 0.1 *M* LiOD neutralized with D_2SO_4. One Pd sample was a 0.1 cm rod obtained from Texas A&M University.

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Table 1. SUMMARY OF CALORIMETRIC RESULTS

Published reports, manuscripts submitted or in press.

Research Group	Calorimeter, Cell	Pd type source	Current Density, Voltage	Excess Heat	Controls	Comments References
	B. GROUPS NOT OBSERVING EXCESS HEAT					
1. U. British Columbia Hayden et al.	Flow closed	Englehard bars	to 2.2 A/cm^2	none (10 d)	Pt	[HAY]
2. M.I.T. Wrighton et al.	ISO B open	JM/Aesar rods	69 mA/cm^2 2.9 V	none (> 200 h)	H_2O	no t, n [ALB]
3. Caltech Lewis et al.	ISO B ISO C (Tronac) open	several rods	72-140 mA/cm^2	none (5)	H_2O	no t, n, He [LEW]
4. Naval Weapons Ctr. Miles et al.	ISO open	JM/Wesgo rods	100-200 mA/cm^2 3-5 V	none (1-10 d)	Pt H_2O	no n,γ [MIL]
5. Sandia N.L. Roth et al.	ISO A open	rod & Pd/Li alloy	320 mA/cm^2	none (17, 36 d)		no n, t [ROT]
6. AT&T Bell Labs Fleming, Law et al.	ISO C (Setaram) closed&open	several wire, rod	16-512 mA/cm^2 2-10 V	none (1-40 d)	Pt H_2O	[FLEM]
7. Argonne N.L. Redey et al.	ISO B, ISO C open	JM rod	15-500 mA/cm^2	none (460 h)	H_2O	[RED]

Table 1. SUMMARY OF CALORIMETRIC RESULTS

Published reports, manuscripts submitted or in press.

Research Group	Calorimeter, Cell	Pd type source	Current Density, Voltage	Excess Heat	Controls	Comments References
	B. GROUPS NOT OBSERVING EXCESS HEAT					
8. Free U. Berlin Kreysa et al.	ISO A open	rod, sheet	1.2 A 9 V	none (10 ?)	H_2O	no n,t,γ [FRE]
9. EG&G Idaho Longhurst et al.	ISO A ISO C open	foil, wire	0.1 ma-5.7 A 3.3-5.1 V	none (> 20 cells) (120 h)	H_2O	no n,t,γ [LON]
10. Iowa St. U. Hill et al.	open	rod	0.7-1 A/cm^2	none		no n,γ [HIL]
11. U. Newcastle-upon-Tyne Armstrong et al.	flow open	sheet cube	100 mA/cm^2 15-20 V	none (8 d) (2)	Pt(H_2O)	[ARM]
12. Harwell Lab. Williams et al.	ISO A ISO C-type open	JM rod, cast, beads, ribbons	20-530 mA/cm^2 3-15 V	none (11) (to 33 d)	H_2O Pt (14)	no n, t, γ [WIL]
13. Chalk River Nuclear Labs. D.R. McCracken et al.	Flow closed	JM rod	150-300 mA/cm^2	none (2) (18, 47 d)		no n, t [MCC]

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Table 2. Internal and Unpublished Reports and Private Communications on Calorimetric Results[a]

A. Groups Observing Excess Heat or Bursts in Some Cells

1. U. Landau—Case-Western Reserve University
2. E. Yeager, B. Cahan, R. Adzic—Case-Western Reserve University
3. D. Hutchinson—Oak Ridge National Laboratory
4. C. Scott—Oak Ridge National Lab.
5. A. Schessow—University of Florida
6. B. Liebert—University of Hawaii
7. T. Droege—Batavia, Illinois
8. G. Balding—Nytone Electronics
9. H. T. Hall, Jr.—Novatek
10. M. Wadsorth—University of Utah
11. M. McKubre—Stanford Research Institute

B. Groups Reporting No Excess Heat in Any Cell

1. C. Martin, B. Gannom, K. Marsh et al.—Texas A&M University
2. S. Gottesfeld—Los Alamos National Laboratory
3. S. Little et al.—Austin, TX
4. D. Bennion—Brigham Young University
5. W. Ayers—Electron Transfer Technologies
6. R.P. Allen, J.R. Morrey et al.—Battle Northwest DOE Laboratory
7. T. R. Jow, E. Plichta et al.—U.S. Army ETDL
8. H. W. Randolph—Westinghouse Savannah River Site
9. H. Weissman—Brookhaven National Laboratory
10. P. Ross—Lawrence Berkeley Laboratory
11. F. Wagner—General Motors Corp.
12. J. C. Farmer—Lawrence Livermore National Laboratory
13. E.L. Fuller, Jr. et al.—Oak Ridge National Laboratory

[a] Experimental conditions generally the same as those in Table 1.

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MATERIALS CHARACTERIZATION SECTION

INTRODUCTION

Relatively little emphasis has been placed on the role of material properties in "cold fusion" experiments. Characterization of the anode and cathode compositions, microstructures, homogeneity, etc. generally has not been carried out and has not played a significant role in the discussions directed towards understanding "cold fusion". These materials parameters have however been invoked in discussions directed towards explaining difficulties associated with reproducibility in these experiments. Most experimental protocols have utilized Pd cathodes for the electrolytic charging and Ti (or Ti alloys) for gas charging experiments following the examples of the initial experiments by Fleishmann and Pons (FLE), and Jones (JON). In addition, most electrolytic charging experiments have utilized Pt anodes, with the important exception of those at Texas A&M which are reporting T generation and which utilize Ni anodes (BOK).

STOCHIOMETRY ATTAINED

It has become increasingly common for the D/Pd ratio attained to be reported in the electrolysis experiments. Measurements of the D concentration are often based on the weight gain of the cathode during electrolysis. Values of D/Pd in the range 0.7 to 1.1 have been commonly reported for experiments which report both positive and negative "cold fusion" results. The gravimetric method of measurement is generally relatively reliable for D/Pd values in the range of 0.6 to 1; as long as the loss of D is minimized between the period of charging and the weighing. Most investigators do not report the details of their procedures. Measures taken to avoid loss of D, such as the storage of specimens at low temperature, are not discussed. An additional difficulty in the electrolytic charging experiments is that deposits on the cathode or "diffusion" of Li into the cathode must be accounted for properly before the gravimetric results can be considered accurate. In the majority of the reported results, it has not been shown that suitable procedures have been carried out.

CATHODE CHEMICAL ANALYSIS

In a few cases the cathodes have been analyzed for T, ^{3}He, and ^{4}He after electrolysis: with negative results (WIL). In most experiments these analyses have not been carried out despite the importance of these fusion products in establishing the presence or absence of "cold fusion". Reports of diffusion of Li into the cathodes have been made (BOK) but the bases for these reports have generally not been specified. In one case (WIL), the presence of Li up to several micrometers into the Pd cathode was detected by Secondary Ion Mass Spectrometry (SIMS) but the authors suggest that this was the result of surface cracking and contamination of the crack surfaces by the electrolyte. They also detected other components of the electrolyte on the cathode surface.

Even less materials characterization has been carried out for the gas charging experiments. Often mixtures of metals have been used and they have been characterized as "turnings", "sintered powder", "mossy solids" etc.; none of which have any meaning with respect to the material's character. The D/Pd ratios have generally not been determined nor has sufficient information been given to even allow an estimate to be made. In some cases, the pressure of the D_2 gas above the material has been measured and shown to decrease during periods when the materials was to have absorbed D. It is important to determine the D/metal ratio in these experiments as absorption of D in Ti and its alloys is a very surface sensitive process. Exposure to D_2 gas does not assure that significant absorption of D occurs.

RELEVANT MATERIALS PARAMETERS

As discussions of the success or failure of "cold fusion" experiments have often been ascribed to properties of the cathode materials, it is useful to consider the various materials parameters suggested to be significant. In the following, these will be considered in light of what is known of the behavior of D(H) in Pd and Ti.

a. Success of the electrolytic "cold fusion" experiments has been ascribed to the very high deuterium "confinement pressures" achieved at the cathode at the electrolytic overpotentials applied. Fleischmann and Pons (FLE) discuss equivalent D_2 pressures of about $8x10^{26}$ atm. corresponding to their overpotential of 0.8 V. As discussed in Appendix - - , the overpotentials do result in a high deuterium fugacity at the Pd surface. However, the non-ideality of D_2 gas and the loss of deuterium by D_2 bubble formation at the surface results in a much decreased equivalent D_2 pressure. The relation between fugacity and equivalent pressure is not easily obtained as it depends sensitively on the surface structure and impurity concentration. However, at steady state, i.e. after long charging times, the D in the specimen is at the same chemical potential as that at the surface. Hence the H(D)/Pd values obtained by cathodic charging may be compared to those obtained by gas charging (BAR). Upon making this comparison, it is seen that the compositions attained by cathodic charging correspond to a very moderate D_2 pressure of 15 kbars. While high fugacities are produced by the overpotentials used in cathodic charging, confinement pressures of the order discussed by Fleischmann are not produced.

b. The suggestion has been made that as a result of the high fugacity, confinement of D in Pd results in a very small D-D distance. As discussed in Appendix -- the smallest distances between interstitial sites occupied by D in Pd is 0.17 nm; which is large compared to the D-D distance in the D_2 molecule. Significant dual occupancy of interstitial sites by D is not in accord with the linearity of the lattice expansion measured by x-rays (PEI) or with theoretical treatments of the Pd-D system (NOR)(RIC). Furthermore, multiple occupancy of vacancy sites (BES) leads to an increased D-D spacing. Thus even under the high D/Pd values attained by electrolytic charging the D-D spacing remains much too large for any fusion reaction.

c. The suggestion has been made that successful experiments require very long charging times. As discussed in Appendix --, the diffusivity of D in Pd is sufficiently large at 300 K so that equilibrium can be attained in a 1 cm thick sheet of Pd in times of the order of 7 days. In the 1 mm thick cathodes often used, the time to attain equilibrium at 300 K is of the order of 2 hrs. These times are very much shorter than the very long times which, it is often claimed, are required for successful "cold fusion" experiments.

d. The suggestion (PON) that a particular form of the cathode material, e.g. cast material, must be used for successful "cold fusion" experiments is not in accord with what is known about the behavior of Pd. Annealing the material to minimize the dislocation concentration should not be necessary. The very large inhomogeneous deformations which accompany cathodic charging of Pd, under the conditions used, result in high dislocation densities even in a well annealed material (HO). Furthermore, the suggestion that vacuum annealing is necessary to remove the interstitial impurities (HUG) does not seem to be in accord with the conditions under which "cold fusion" is claimed. At the high D/Pd values, the presence of a few interstitial or dislocation trapping sites is insignificant compared to the high D concentrations.

e. Deposition of various materials from the anode and from the electrolyte (leached from the container) on to the cathode has clearly occurred in many of the experiments. Analysis (WIL) has revealed Pt (probably from the anode), Si (probably leached from the glass container), Cu, Zn, Fe, Pb, and other trace elements. Surface contamination of the cathode may affect the rates of reactions and therefore the effective fugacity. In general, surface poisons increase the fugacity by decreasing the rate of D_2 formation. This is indicated by the high D/Pd values attained and by the observation, reported in several experiments, that the loss of D from the cathode after electrolysis was slow. Thus surface contamination probably had the effect of increasing the D/Pd values and the fugacities attained.

"Dendritic" growths were reported on the surfaces of the cathodes in the Texas A&M experiments which utilized Ni anodes (BOK). This has lead to the suggestion that these dendrites are of significance for the formation of T during electrolysis, possibly "due to increased electric fields at the dendrite tips" (BOK). Other experiments which reported these "dendrites" have not reported generation of T (WIL). It is difficult to understand the importance of these "dendrites" in "cold fusion". (These dendritic growths are not uncommon in plating experiments.) The field at the "dendrite tip" is the voltage across the double layer divided by the thickness of the layer. Since the total voltage across the double layer at the cathode is of the order of several volts, high fields can be attained if the double layer thickness is small. However, acceleration of D^+ ions across this double layer will only result in energies of several eV (the energy determined by the voltage drop at the cathode); hardly enough to cause fusion.

f. The conditions of the gas charging experiments are likely to result in hydride formation in the Ti-D system and formation of the β phase in the Pd-D system. The process of gas charging is well understood, as is the process of discharging of D into the gas phase from hydrides. Anomalous behavior which may lead to the fusion of D solutes and the formation of fusion products is not expected in these processes. Fracture of the brittle hydride phases is likely and has been well studied (SHI a). These fracture processes are of low energy and occur at a fraction of the speed of sound in hydride. While acceleration of charged particles have been suggested to occur during fracture, this phenomenon remains speculative. Even if it were to occur, it appears to be unlikely that D energies sufficient for "cold fusion" could be generated from the release of energy characteristic of the fracture processes. There is little reason for these fracture processes to lead to "cold fusion" and the generation of neutron bursts; absent some heroic, imaginative and as yet unfounded mechanism.

CONCLUSIONS

The behavior of H(D) in Pd and Ti are sufficiently well understood to answer many of the speculations about the properties of these interstitials under the conditions for which "cold fusion" has been reported. The behavior of these solutes has been well explored using both experimental and theoretical techniques. None of the known behavior is consistent with the possibility of overcoming the coulombic repulsion between the D ion cores. The confinement pressures and energies of D in Pd and Ti are far from the regimes which are required for a reasonable possibility of "cold fusion". No aspect of the known behavior of D in Pd or Ti is compatible with formation of energetic neutrons, tritium or helium.

APPENDIX --: MATERIALS FOR COLD FUSION

"Cold fusion" experiments have utilized two types of cathode materials; palladium and titanium (including several titanium alloys). These two metals have significantly different behaviors in the presence of hydrogen and its isotopes. Their response to exposure to hydrogen isotopes has been extensively studied and well documented (ALE)(MEU); particularly in the case of palladium. In the following, we shall highlight some of the behavior of the Pd-H and the Ti-H systems, selecting those aspects which are most pertinent to the issues raised by the suggested "cold fusion" experiments. Much of what is known derives from experiments using the mass one isotope, H. The isotopic dependence is sufficiently well understood to allow the behavior of deuterium, D, to be deduced from the measurements on H where data on D are not available. Many aspects of the behavior of hydrogen isotopes in body centered cubic (bcc) (β phase Ti alloys) and face centered cubic (fcc) (Pd) metals result from their behavior as quantized particles; other properties can be understood using classical concepts. Behavior as quantized particles has not been established for hydrogen isotopes in the hexagonal close packed (hcp) crystal structure (titanium, α phase Ti alloys) but such behavior may be expected.

A. The Palladium - Hydrogen (Deuterium) System

Palladium has a (fcc) close packed crystal structure and as hydrogen is added, this structure is maintained across the phase diagram (WIC). It can absorb large quantities of H(D) with concentrations as high as H/Pd = 1.1 being attainable. The H(D) occupies predominantly octahedral interstitial sites, which if they were all filled would result in a H(D)/Pd ratio of 1. Hydrogen can also be accommodated in tetrahedral interstitial sites at a somewhat higher energy and it is believed that these sites may be partially occupied at the higher H(D)/Pd ratios. The spacing of H(D) occupying these sites is not particularly small as shown by the Table A below. Both the octahedral and tetrahedral sites have cubic site symmetry. Since H(D) appears to have random distribution in the occupied sites, the maintenance of the cubic crystal structure on adding H(D)is consistent with the high

Table A

DEUTERIUM - DEUTERIUM DISTANCES

SITES OCCUPIED	DISTANCE IN NANOMETERS
nearest neighbor octahedral sites	0.28
nearest neighbor tetrahedral sites	0.19
nearest neighbor octahedral - tetrahedral sites	0.17
D-D distance in a multiply occupied vacancy (BES)	0.19
intramolecular D-D distance in deuterium gas	0.074
intramolecular D-D distance in liquid deuterium	0.074
intermolecular D-D distance in liquid deuterium	0.27
water	0.15

H(D)/Pd values attained. Further evidence for the random occupancy of sites and the cubic distortion of the lattice is provided by x-ray studies of the Pd-H(D) system (PEI) which also indicate that the behavior of D is closely similar to that of H.

Recent theoretical treatments (RIC)(NOR) show that H(D) does not attain exceptionally close nearest neighbor distances; even under dynamic conditions. Molecular dynamic simulations (RIC) at concentrations up to D/Pd = 1.1 found no D-D distances shorter than 0.07 nm compared to the molecular D-D distance of 0.074 nm. Interactions of D with lattice defects have been studied both experimentally and theoretically. Significant attractive interaction energies are found (BES) with those defects, such as vacancies, which have a decreased electron density. Palladium has such an attractive interaction between H(D) and vacancies, but it is particularly weak. Each vacancy can accommodate up to 6 D interstitials with the D solutes occupying sites displaced towards the octahedral interstitial sites adjacent to the vacancy. The D-D distance adjacent to the vacancy is 0.18 nm.

The phase diagram of the Pd-H(D) system (ALE)(MEU) is typical of many of the bcc and fcc hydride forming systems and is shown in Figure 1. The dominant feature is a miscibility gap with a critical temperature of about 549 K and a critical composition of H(D)/Pd ≈ 0.27.

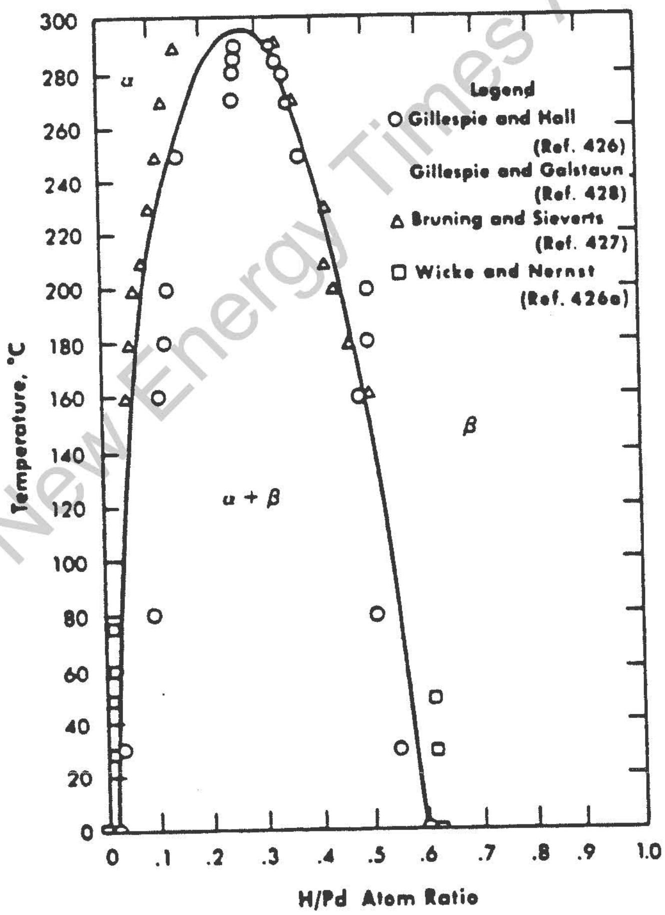

Figure 1. Phase Diagram of the Palladium - Hydrogen System

At about 300 K the initial α phase has a solubility of about H/Pd = 0.03 and the two phase region extends to about H/Pd = 0.6 at which point the β phase is formed. Both the α and β phases have fcc structures. Phase relations in the Pd - H system depend on the isotope of hydrogen used but the differences are not very large. Important differences do exist in the P-C-T data (ALE)(MEU) which characterize the equilibrium of gaseous hydrogen isotopes with Pd. These differences are consistent with the differences in the isotopic masses. Many of the thermodynamic properties of the Pd - H(D) system are consistent with theoretical calculations based on mean field theory (WAG) based on a repulsive nearest neighbor interaction between H solutes. This repulsive interaction has been measured using a variety of methods (WAG)(VOL)(PIC)(OAT).

While the α and β phases are solid solutions of H(D) in the Pd interstitial sites, formation of long range ordered structures does occur at high concentrations and low temperatures (ELL). These structures form by ordering of the H(D) interstitials on subsets of the interstitial sites and are consistent with nearest neighbor deuterium repulsive interactions. At H(D)/Pd = 1 the structure is of course ordered if the H(D) occupies octahedral interstitial sites. No hydrides are known to form at temperatures of the order of 300 K in the high concentration region of the phase diagram. Few careful investigations have been carried out in this region. Lattice parameter measurements (PEI), which extend into this composition region, indicate a linear lattice expansion in the α and in the β phases up to H/Pd = 1.0. The lattice expansion due to H and to D are very similar.

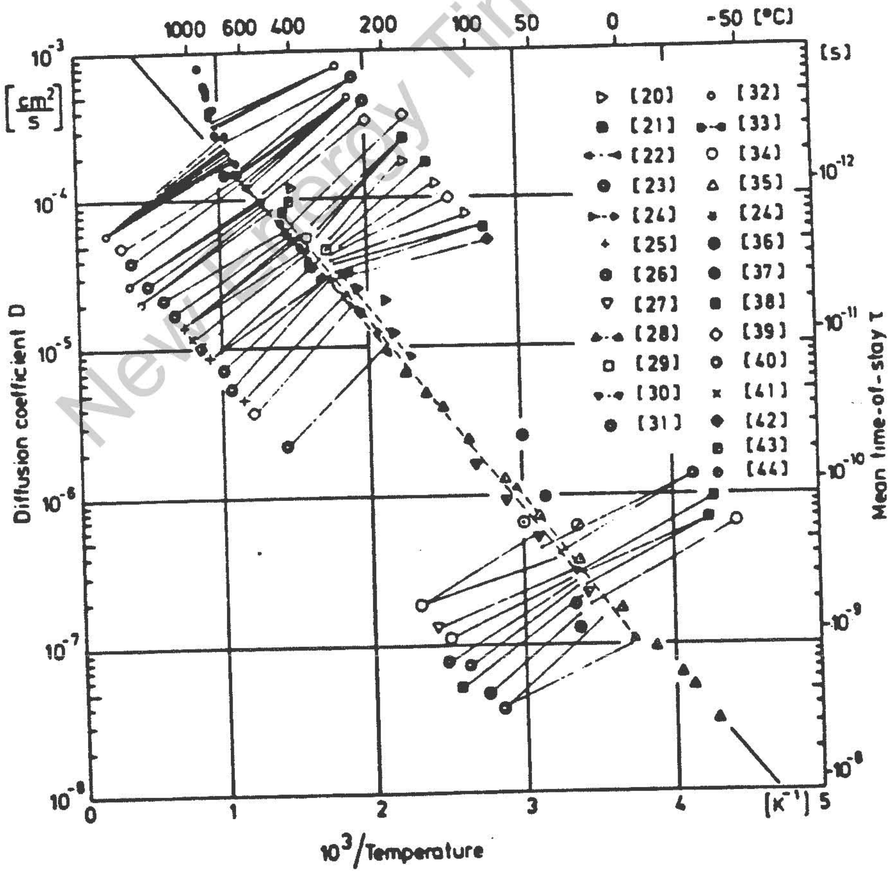

Figure 2. Hydrogen Diffusivity in Palladium

Hydrogen and its isotopes diffuse very rapidly in the Pd lattice (VOL) as shown in the Figure 2. At 300 K, the diffusivity of H in the α phase is about 4×10^{-11} m^2s^{-1}. Hydrogen diffusivity in the β phase is somewhat slower but is still very high. The effect of isotopic mass on diffusivity is very non-classical in Pd with $D_D > D_H > D_T$ at 300 K; a clear indication of the quantum mechanical tunneling process which dominates the diffusion of H(D) in the Pd lattice. H(D) interacts with solutes and lattice defects, both of which can act as "traps" or low energy sites. The presence of these traps decreases the effective diffusivity of H(D) when they are unsaturated, i.e. at low H(D) concentrations. Under cathodic charging conditions, which correspond to high H(D) concentrations, the defect or solute traps are saturated and the diffusivity is little affected by their presence. With respect to the "cold fusion" experiments, an important point is that the known diffusivities of D in Pd allow equilibrium in times considerably shorter than those stated as necessary for attainment of "cold fusion". For example, a time of the order of 7 days is required to achieve equilibrium during the charging of a 1 cm thick sheet specimen and a time of the order of 2 hrs is required for a 1 mm thick sheet.

Hydrogen charging of Pd can be carried out in several ways. Electrolytic charging with the Pd as a cathode has been carried out in a number of different electrolytes. In general, the Pd surface is highly active towards the dissociation of the H_2 (D_2) molecule. Little H_2 (D_2) gas is evolved until relatively high H(D)/Pd ratios are obtained. Additions of "poisons", such as As ions, to the electrolyte increase the fugacity of the H(D) at the surface by decreasing the

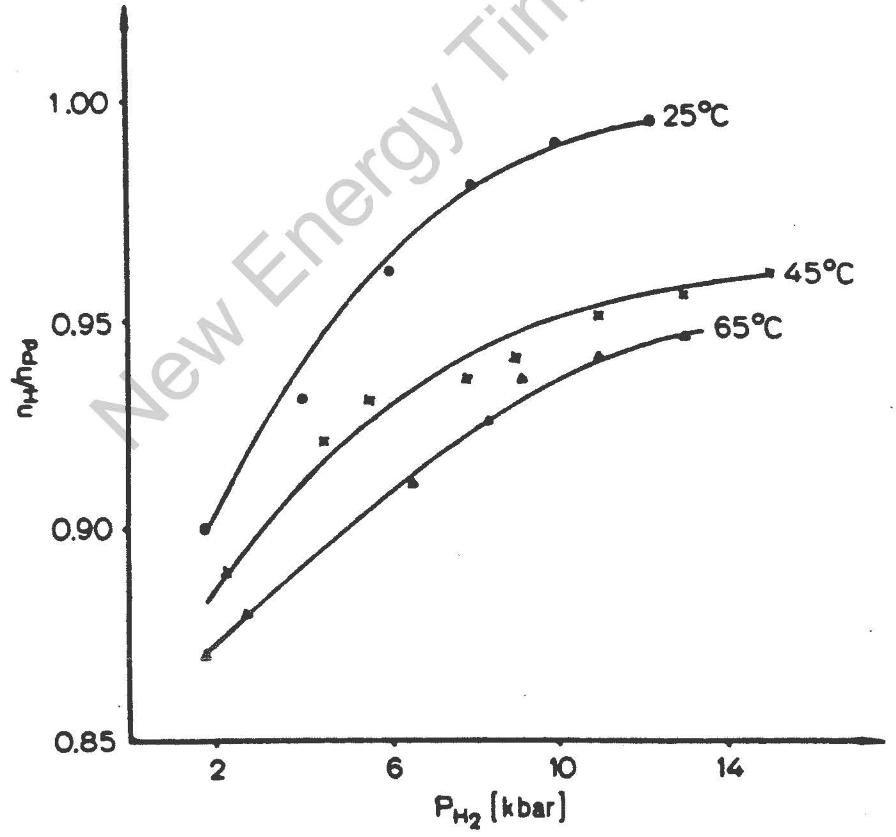

Figure 3. Concentration of Hydrogen in Solid Solution vs Gas Pressure

formation rate of H_2 (D_2). A higher H(D)/Pd value can then be obtained with the same overvoltage. Since the fugacity of hydrogen depends on the overvoltage, as well as on the surface conditions, it is difficult to obtain a direct relation between the cathodic charging conditions and the H(D)/Pd values obtained. Although the units of fugacity are identical to those of pressure, the non-ideality of H_2 (D_2) results in the equivalent pressure at high fugacity being many orders of magnitude less than the fugacity. A calibration of the equivalent pressure can be obtained by equilibrating the Pd alternatively with both an electrolytic potential and a high pressure H_2(D_2) gas at the same H(D)/Pd value.

Gaseous charging of hydrogen is also commonly carried out (BAR). High H(D)/Pd ratios can be obtained for relatively moderate pressures as shown in the Figure 3. Solution of H(D) in Pd follows Sieverts law at low pressures and then shows significant deviations from ideal solution behavior, probably as a result of H(D) - H(D) interactions in the Pd. In the region of Sieverts Law behavior, the proportionality of the H(D)/Pd to the square root of the gas pressure is further evidence for solution of H(D) in Pd in the atomic form; rather than as a molecule.

Concentrations of D/Pd $\approx$ 1 are often attained in "cold fusion" experiments and are often quoted as a necessary condition. It has also been suggested (FLE) that the very high confinement pressures produced by electrolytic charging" are necessary for "cold fusion. Comparison of the D/Pd values attained by gaseous charging with electrolytic charging allows an estimate of these "confinement pressures" to be made. A concentration of about D/Pd $\approx$ 1 requires a gas pressure of about 15 k bars (about 15,000 atm.) at 300 K (BAR) as shown in Figure 3. Thus the effective pressure corresponding to the high fugacities calculated from the overvoltages during cathodic charging are equivalent to very moderate pressures indeed.

Palladium is an "exothermic occluder" of H(D), i.e. the heat of solution, relative to the gas phase as a standard state, is negative. The heat of solution is relatively small having a value of -19 kJ/mole H_2 in the α phase (MEU)(WIC) a value of about -46 kJ/mole H_2 in the β phase. The heats of formation of the hydrides in the Pd - H(D) system have not been measured. Hydride heats of formation of many other systems have been measured, are generally exothermic, and lie in the range -58 to - 209 kJ/mole H_2 (MEU). There is only a small effect of isotopic mass on these values. The significance of these values is that the molal enthalpy change on forming the deuteride from a solid solution of the same concentration would be the (heat of formation of the hydride) - (the heat of solution). This value is about -150 kJ/mole or less and represents the upper limit of the heat released from the specimen due to an ordering reaction at high concentrations of D.

Formation of the β phase from the α phase during charging causes a large amount of lattice strain and deformation (MAN) as a result of the large increase in volume. Since the molar volume of the β phase is larger than that of the α, the β phase is in compression during charging and plastic deformation occurs in the α phase. On removing the H(D) the decrease of volume which accompanies the β to α phase change causes very high tensile stresses and surface cracking.

B. The Titanium - Hydrogen (Deuterium) System

While considerably less is known about the Ti - H(D) system than about the Pd - H(D), our knowledge is sufficient to answer many of the questions of interest for the "cold fusion" experiments. HCP titanium absorbs H(D) in the α solid solution up to concentrations of about H(D)/Ti ≈ 0.05 at 300 K. Low temperature measurements are not very accurate due to difficulties in absorbing H(D) from the gas phase caused by surface oxides. Above this concentration a two phase equilibrium exists between the hcp α solid solution and the γ hydride. This hydride exists over the composition range $TiH(D)_{1.9}$ to $TiH(D)_2$. The hydride has a flourite fcc structure at the lower compositions and a face centered tetragonal structure as the H(D) concentration is increased. At temperatures above about 570 K the α phase H(D) solubility is about H(D)/Ti ≈ 0.1 and the solid solution is in equilibrium with the bcc β phase as shown in the phase diagram shown in Figure 4. The β phase has a very high solubility for H(D) of the order of H(D)/Ti ≈ 1. Above this composition the β phase is in equilibrium with the γ dihydride, $TiH(D)_2$. Since the β phase of Ti can be stabilized to below 300 K by solute additions, it is possible to absorb large quantities of H(D) into the β stabilized alloys at temperatures near 300 K without forming hydrides. The extent of this low temperature H(D) solubility in the β stabilized Ti alloys has not been established (SHI b). Gas phase "cold fusion" experiments have utilized Ti alloys as well as unalloyed Ti. In

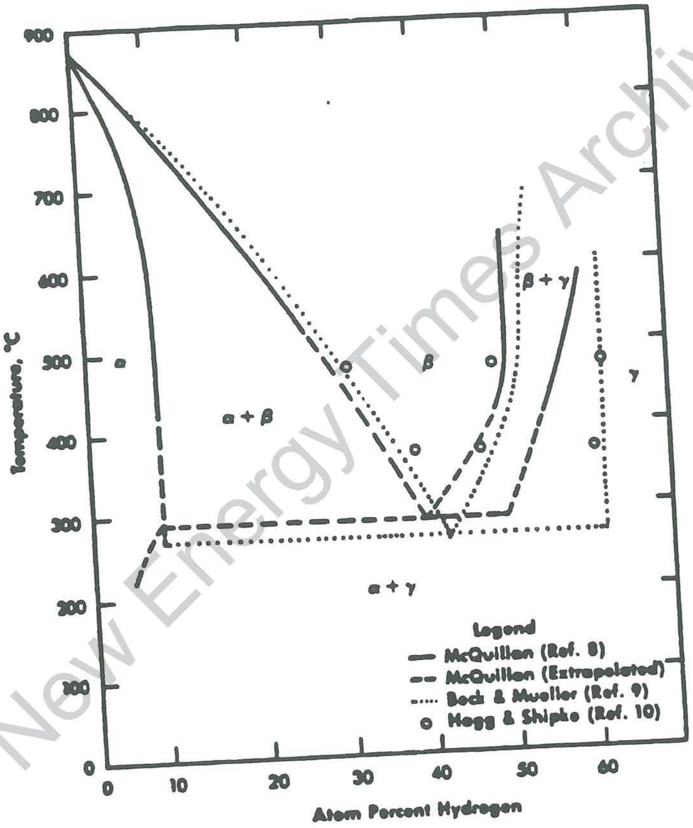

Figure 4. Titanium - Hydrogen Phase Diagram

some cases these alloys have been specified to be Ti-6Al-6V-2Sn (MEN) which is a α – β alloy, i.e. it was a two phase alloy mixture of the hcp and bcc phases. These two phase alloys have been studied in H atmospheres without noting unusual behavior with respect to the properties of H.

Site location studies have been carried out for some of the Ti - H(D) structures. Random occupancy of tetrahedral sites in the non-stochiometric γ hydrides was deduced from NMR measurements (STA a). The nearest neighbor D-D distances in the γ hydride phase (SID) is shown in the Table B below. If we assume tetrahedral site occupancy in the hcp α phase and both octahedral and tetrahedral site occupancy in the β phase, the nearest neighbor distances given in the Table B below can be calculated. As can be seen, these are larger than the D-D distances in the molecule and much larger than the distances required for fusion.

Table B

DEUTERIUM - DEUTERIUM DISTANCES IN TITANIUM

α PHASE (HCP)	D - D Distance in nm
nearest neighbor tetrahedral sites	0.23
γ PHASE (FCC)	
nearest neighbor sites	0.22
β PHASE (BCC)	
nearest neighbor octahedral sites	0.17
nearest neighbor octahedral-tetrahedral sites	0.083

The thermodynamics of the Ti - H(D) system has been extensively studied. Heats of solution for H(D) in the α and the β phases are exothermic as is the formation of the γ hydride. The isotopic mass dependence is very small. These enthalpies are given in the Table C below (STA b)(STA c)(MCQ)(HAG)(MOR). Since the heats of solution are negative (exothermic), Ti and its alloys absorb D as they are cooled in D_2 gaseous atmospheres and desorb D on heating.

While diffusion of H(D) in Ti has not been measured, the diffusivity at 300 K can be deduced from permeation experiments to be about 1×10^{-10} m^2s^{-1}. This diffusivity would allow equilibration of a 1 mm thick sheet with the H(D) gas atmosphere in about 0.7 hrs. Equilibration of Ti with gaseous H_2 at low temperatures is slow due to surface oxides which inhibit the entry processes. Even under cathodic charging conditions entry of H(D)

Table C

ENTHALPIES OF SOLUTION AND FORMATION
(kJ / mole H2)

	HYDROGEN	DEUTERIUM
solution in α phase	-90.4	-94.6
solution in β phase	-116.4	
formation of γ phase	-138	-121

is inhibited unless the surface oxide is minimized and "electrolytic" poisons used to minimize the recombination reaction which leads to H_2 formation at the surface. As a consequence, equilibration in a gaseous atmosphere or under cathodic charging is dominated by surface reactions.

Titanium hydrides are brittle and undergo cleavage when stressed. Hydride formation in α phase alloys causes embrittlement (SHI a). The β phase alloys are much less susceptible to embrittlement and can absorb large quantities of H(D) without fracturing. The tendency to fracture during absorption and desorption of H(D) is clearly associated with the hydride (deuteride) formation and the large volume changes which accompany these phase changes. It is not surprising that the gas charging "cold fusion" experiments report fracturing of the Ti specimens used as the D is absorbed and desorbed. This fracturing is most likely to occur during the heating of specimens which have absorbed large quantities of D. During the cooling cycle the Ti absorbs D from the gas phase and the D composition gradient (and its accompanying molar volume gradient) causes a compressive stress at the outer portion of the specimen. During the heating portion of the cycle the loss of D causes tensile stresses at the outer parts of the material and these cause the fracture to occur.

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APPENDIX A

The Secretary of Energy
Washington, DC 20585

April 24, 1989

Mr. John H. Schoettler
Chairman
Energy Research Advisory Board
US Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Mr. Schoettler:

In recent weeks, there has been a great deal of interest in the prospects for "cold fusion", based on experiments at universities in Utah and subsequent experiments performed elsewhere. At present, the apparent observations of cold fusion and significant quantities of energy from this phenomena are being investigated extensively. Because of the potential benefits from practical fusion energy, I request that the Energy Research Advisory Board (ERAB) assess this new area of research. Specifically, I would like the Board to:

1. Review the experiments and theory of the recent work on cold fusion.

2. Identify research that should be undertaken to determine, if possible, what physical, chemical, or other processes may be involved.

3. Finally, identify what R&D direction the DOE should pursue to fully understand these phenomena and develop the information that could lead to their practical application.

I request that the Board provide an interim report on the first item by July 31 and a final report on all items by November 15, 1989.

Sincerely,

James D. Watkins
Admiral, U.S. Navy (Retired)

APPENDIX B

ENERGY RESEARCH ADVISORY BOARD
COLD FUSION PANEL

6/02/89

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APPENDIX C

PANEL MEETINGS AND SCHEDULE OF LABORATORY VISITS

PANEL MEETINGS

Washington, DC	June 22, 1989
Washington, DC	July 11-12, 1989
Chicago, IL	October 13, 1989
Washington, DC	October 30-31, 1989

SCHEDULE OF LABORATORY VISITS

University of Utah	June 2, 1989
Brigham Young University	June 13, 1989
Texas A&M Univeristy	June 19, 1989
California Institute of Technology	June 20, 1989
Stanford University	July 6, 1989
SRI International	July 6, 1989

OTHER

Workshop on Cold Fusion, Santa Fe, NM	May 23-25, 1989

ROUGH DRAFT

UPDATE ON THE MEASUREMENT OF NEUTRON EMISSION FROM TI SAMPLES IN PRESSURIZED D_2 GAS

H. O. Menlove and E. Garcia
Los Alamos National Laboratory
Los Alamos, NM 87545

During the Workshop on Cold Fusion Phenomena, Santa Fe, New Mexico, May 2, 1989, we reported [Los Alamos National Laboratory report LA-11686-C (September 1989)] on the measurement of neutrons emitted during pressurized D_2 gas experiments using Ti and Pd samples. The experimental program has continued since the Santa Fe meeting, and our data base has more than doubled.

Our recent work has included detector upgrades, background investigations, acoustical emissions, and sample preparation and procedure investigations. This report will give a brief summary of our work in the above areas.

I. DETECTOR UPGRADES

We are using four independent ^{3}He neutron detector systems for our experiments. All of the systems use ^{3}He tubes in polyethylene (CH_2) moderators to detect the neutrons. The detector characteristics and background levels are given in Table I.

A. Background Neutrons

We have reported results for both random neutron (totals) emission and time-correlated (coincidence) neutron emission. The background random neutrons originate primarily from cosmic-ray interactions in the detector, shielding, and sample, as well as radioactive decay of uranium in the concrete shielding and α and β decay in the ^{3}He tube walls. On the other hand, the time-correlated neutrons originate from cosmic-ray spallation reactions in the sample and detector body. If the spallation reaction takes place at a significant distance from the detector tubes, the small solid angle and intervening shielding between the spallation and the detector prevents the detection of a coincidence event.

To investigate neutron background fluctuations, we counted the neutron backgrounds from the the dummy sample for periods of 3 weeks for System 4 and 2 weeks for System 3 and showed that the observed scatter of random counts (10^4-s time intervals) about the mean [illegible] the expected standard deviations (RSD) of 1.6% for System 4 and 2.0% for System 3.

Recently, the external neutron backgrounds in Systems 1, 2, and 3 have been reduced by the addition of 10 to 30 cm of CH_2 to the exterior of the detectors. These lower rates are reflected in Table I.

B. System 3 Upgrade

An electronic noise veto counter has been added to System 3. Figure 1(a) shows a schematic diagram of the upgraded system. The split of the high voltage to the external set of five ^{3}He tubes is used to pick up possible electronic noise such as voltage spikes and rf interference. The external tubes have no CH_2 and they are wrapped in cadmium so they have negligible efficiency for counting neutrons. Their coincidence rate is less than 1 count per day. A coincidence count in this external counter vetoes a count in any of the other systems.

C. System 4 Upgrade

A third ring of ^{3}He tubes has been added to System 4 as shown in Fig. 1(b). Ring 3 has completely independent electronics from the two inside rings and it measures the sample neutrons with an overall efficiency of 5%. The ratio of totals counts between the inside detector and ring 3 is 6/1 and the corresponding coincidence count ratio is 46/1.

The ring ratio can be used to show that the neutrons originated from the sample, and for larger bursts, the ratio can be used to establish the average neutron energy.

D. Neutron Die-away Time

For System 4, we have split the output from the inside detector to two different coincidence electronics, as shown in Fig. 1(b). The normal shift-register[1] has a coincidence gate of 128 µs and the second shift register has a gate of 32 µs. A ^{252}Cf source was used to show that an instantaneous burst of neutrons results in a coincidence ratio in the two gates (128 µs/32 µs) of 2/1. We now check that our background and sample burst events satisfy this ratio. This is essentially a measure of the neutron die-away time (~50 µs) in the detector.

Typical sources of electronic noise will not satisfy this gate ratio criteria.

III. NEUTRON BURST RESULTS

We have continued to measure neutron bursts from the Ti samples in D_2 gas; however, the events are unpredictable and difficult to obtain. Table II gives a list of the samples that have yielded neutron bursts. The list shows the number of source neutrons, and the underlined values correspond to events that occurred during warm-up from liquid nitrogen (LN) temperatures at approximately -30°C. The samples in parenthesis were marginal performers, and they are on the borderline between active and inactive samples.

Table III lists the samples that were inactive in that they yielded no neutron bursts. Four of the inactive samples were H_2 gas control samples and six were deuterided Pd samples. All of the H_2 samples have been inactive and they are currently being used for the dummy samples.

Most of the samples from Ti-12 to Ti-36 have used variations of the alloy Ti-6, 6, 2 (6% Al, 6% V, 2% Sn) or Ti-6, 4 (6% Al, 4% V). The metal bar stock is cut into small turnings (~1 by 1 by 3 mm) using a lathe.

An example of an active sample data run is shown in Fig. 2, where the coincidence counts per 2000-s time interval are plotted vs the counting time. The large emission at about 195 h occurred about 40 min after removing the sample from the LN following a D_2 gas refill.

The relationship between the neutron bursts and the LN temperature cycle[2] continues. The underlined values in Table II show that the majority of neutron bursts occur during warm-up from LN; however, this time period while the sample is between -100°C and 0°C represents less than 2% of the sample counting time. The dummy samples and control samples have *never* given a burst during their equivalent warm-up period.

This dramatic relationship between the LN cycle and the bursts is illustrated in Fig. 3, where the burst frequency is plotted as a function of the number of source neutrons. We see that there are a few events as large as 200-300 source neutrons; however, most events are at the low end of the distribution. Sources smaller than ~15 n are lost in the cosmic-ray spallation background.

In Fig. 3, the solid bars represent bursts that occurred at ~-30°C, and the cross-hatched bars correspond to room temperature bursts. It is highly significant that *all* of the high-yield bursts occurred during the LN warm-up at ~-30°C.

For recent experiments, we have attached an accoustic emission sensor[3] to the outside of our stainless-steel cylinders that contain the D_2 gas and Ti chips. The sensor can detect the cracking sounds from the hydriding of the Ti metal chips.

We have found that there is no detectable acoustical emission at the time of the neutron bursts. However, samples that have no- or low-acoustical emission are not likely to yield neutrons. Samples that we thought were the same yielded acoustical emissions that differed by an order of magnitude. Several samples have yielded many thousands of acoustical emissions without any neutron emission.

IV. SUMMARY

W continue to observe infrequent neutron bursts from Ti metal chips and electrolysis residue samples in pressurized D_2 gas. We have been unable to pinpoint the sample characteristics that yield the neutrons. However, we have identified some negative characteristics related to inactive samples such as (1) predeuterided Ti or Pd at high temperature, (2) unstressed Ti pieces that do not crack under the LN temperature cycle. The H_2 control samples have all been inactive.

Ten samples have yielded large neutron bursts with at least 23 bursts at the ~-30°C temperature. A time interval of several days is required between the gas loading and the first neutron yield from the LN cycles. High-efficiency detectors, time-correlation counting, and noise rejection is required to measure the neutron bursts.

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FIGURE CAPTIONS

Fig. 1. (a) Schematic diagram of detector System 3 with the external electrical noise veto counter containing five ^{3}He tubes inside a cadmium absorber. (b) Schematic diagram of detector System 4 with an outside ring of detectors for splitting the signal from the inside detector and dual gate electronics for the inside tubes.

Fig. 2. Neutron time-correlated counts for 2000-s counting intervals vs time for Ti-16. The large burst at 195 h into the experiment occurred during warm-up from LN at −30°C following a refill of D_2 gas in the cylinder.

Fig. 3. The neutron burst frequency vs the yield of source neutrons in the burst. The solid bars correspond to burst events during the LN warm-up at −30°C.

TABLE I. Neutron Detector Characteristics

Identification	Shape	Number ^{3}He Tubes	Total Efficiency[b]	Random Bkg (counts/s)	Coincidence Bkg (counts/h)
System 1	Rectangular channel	18	21	0.23	1.3
System 2	Cylindrical cavity	6	26	0.092	0.35
System 3	Cylindrical cavity	16 + 5	34	0.16	2.3
System 4	Cylindrical cavity	16 + 3	31	0.39	2.3

---

[a] The ^{3}He tubes are typically 30 cm active length and 4-6 atm fill pressure.
[b] The total efficiency was measured using a calibrated ^{252}Cf source located at the sample position.
[c] The coincidence background was measured with a 1.2-kg sample cylinder in the counting position.

7/18	Ti-19	88, 13
8/18	Ti-22	55, 97
8/11	(Ti-23)	19, 23, 19
8/8	Ti-24	35, 119, 16, 16, 16, 15, 15
8/22	(Ti-25)	32
8/24	(Ti-28)	17
8/29	Ti-30	280, 13
9/11	Ti-31A	86, 34
9/12	Ti-32	23, 35

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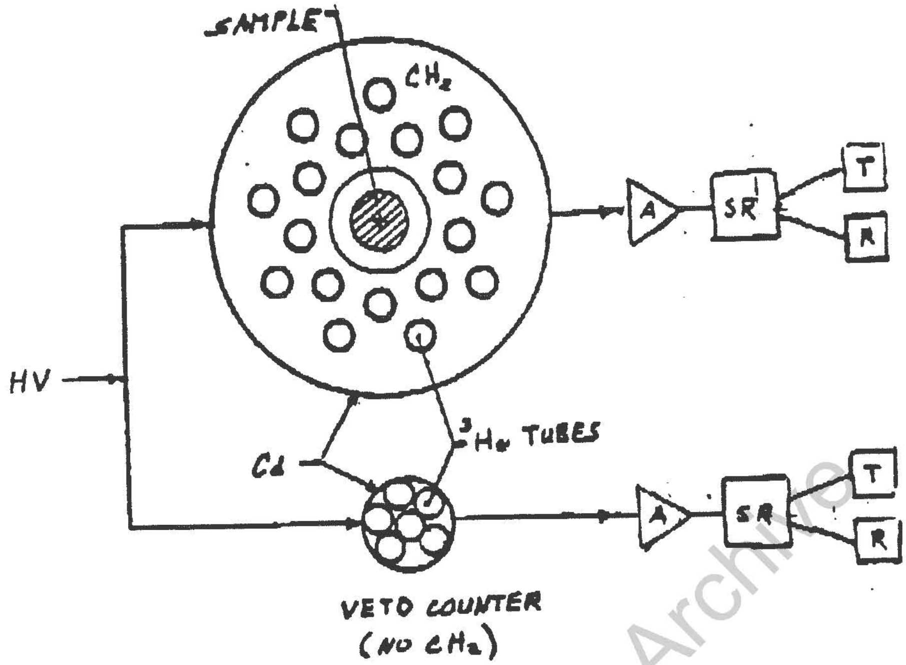
[a] The parenthesis around a sample number indicates a marginal performer that is on the borderline between active and inactive samples.
[b] The underline under the neutron yield indicates that the burst occurred during warm-up from LN temperature.

Table III. Inactive Samples

H_2 Gas Controls	D_2 Gas Ti Samples	D_2 Gas Pd Samples
Ti-27	Ti-2	Pd-1S
Ti-29	Ti-4	Pd-2S
Ti-31`	Ti-5	Pd-3S
Ti-35	Ti-7	Pd-4S
	DD-3	Pd-5L
	Ti-8	
	Ti-9	
	Ti-11	
	Ti-12	
	Ti-15	
	Ti-17	
	Ti-18	
	Ti-20	
	Ti-21	
	Ti-26	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A
SR
T
R
HV
Cd
^3He TUBES
A
SR
T
R
VETO COUNTER
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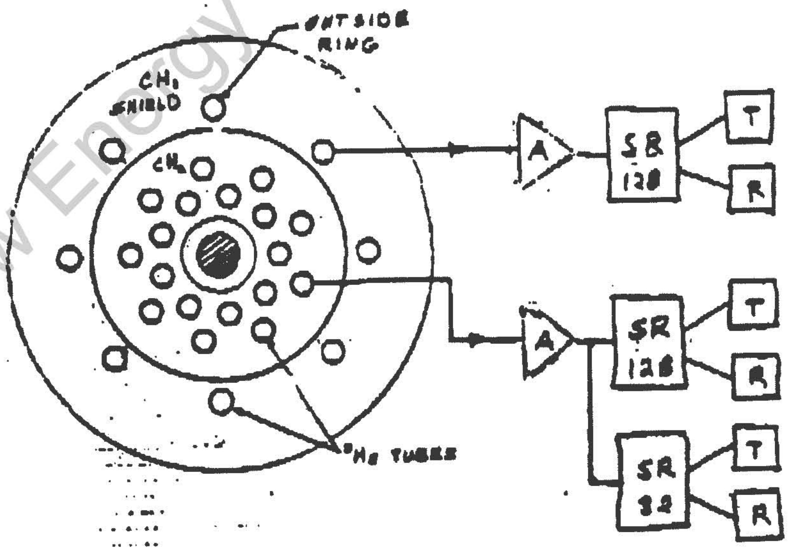
OUTSIDE RING
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CH_2
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R
A
SR 128
T
R
SR 32
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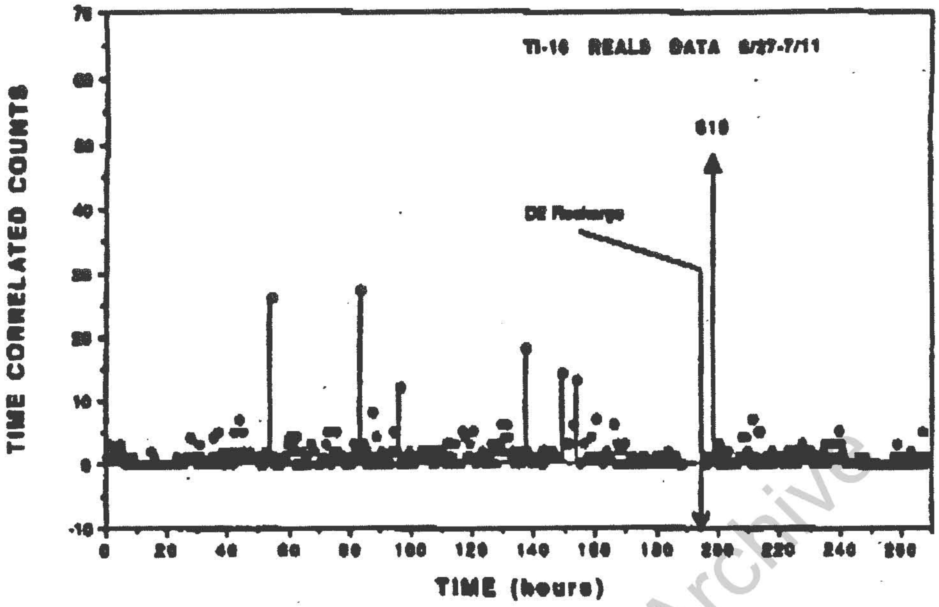
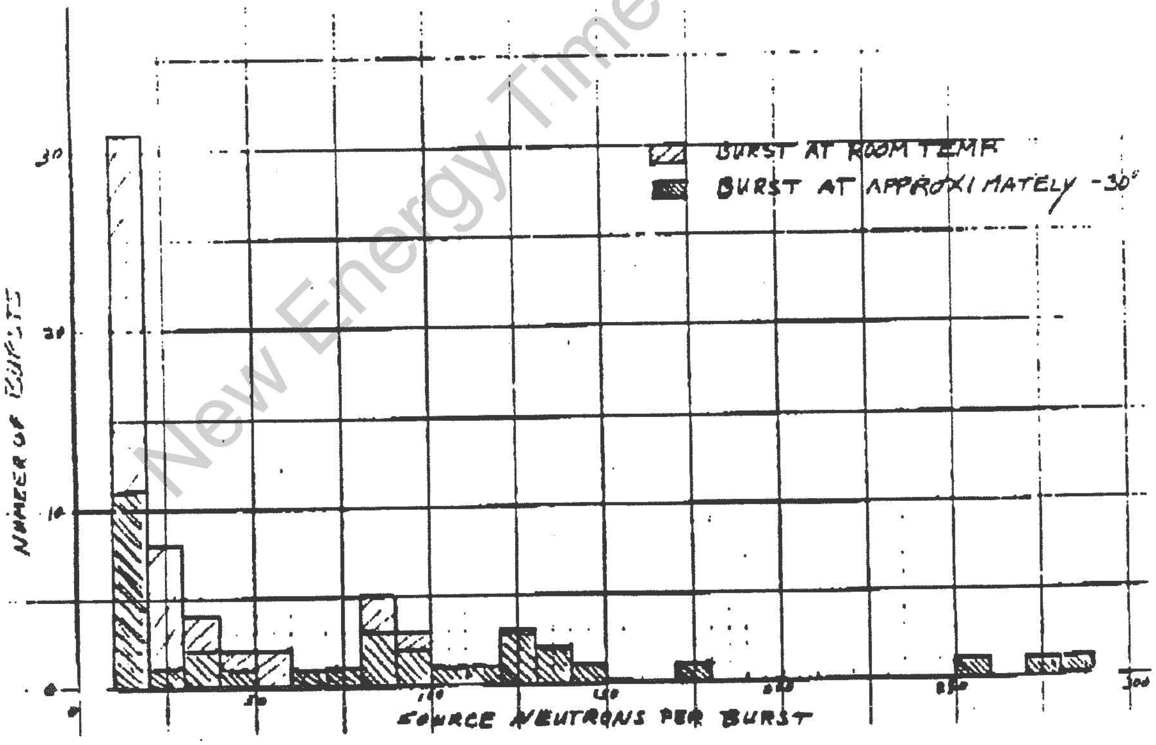
R
^3He TUBES


Ti-16 REALS DATA 6/27-7/11
619
DE Recharge
TIME CORRELATED COUNTS
70
60
50
40
30
20
10
0
-10
0
20
40
60
80
100
120
140
160
180
200
220
240
260
TIME (hours)


BURST AT ROOM TEMP.
BURST AT APPROXIMATELY -30°
NUMBER OF BURSTS
30
20
10
0
0
50
100
150
200
250
300
SOURCE NEUTRONS PER BURST

CHNOLOGY WSJ 10/23/89

Cold Comfort on Cold Fusion Front

By JERRY E. BISHOP
Staff Reporter of THE WALL STREET JOURNAL

HOLLYWOOD, Fla.—The list of laboratories claiming to be producing inexplicable amounts of heat from "cold fusion" experiments is slowly growing.

But the experiments continue to be plagued by lack of firm evidence that the extra heat is coming from the fusing of hydrogen atoms. New experiments at some of the big national laboratories are still unable to find hints of nuclear fusion reactions, leaving only the finding of tritium in a Texas experiment to support University of Utah chemists' claim of achieving hydrogen fusion at room temperatures.

The latest developments in cold fusion research were presented in 24 reports delivered at the fall meeting here of the Electrochemical Society, the first scientific meeting in five months to hear formal reports on cold fusion experiments.

The meeting offered stark evidence of a dramatic fall in scientific interest in cold fusion research. Of the 1,300 chemists registered for the society's weeklong meeting, fewer than 200 sat through the day and a half of cold fusion presentations at week's end. This was in contrast with the society's meeting last May, at the height of the controversy, when more than 1,500 scientists, along with scores of reporters and TV crews, crowded into a Los Angeles hotel ballroom for a tumultuous special night session on the subject.

Neither of the two chemists whose Utah experiments triggered the cold fusion uproar, Martin Fleischmann and B. Stanley Pons, were at the meeting. But some members of an ad hoc expert committee set up by the Department of Energy to evaluate the cold fusion research were in the audience. The committee is to recommend at the end of the month whether DOE should support cold fusion research.

Most of the two dozen scientists taking the podium reported results with new, more sophisticated variations of the seemingly simple electrolysis-of-water experiments described last March by Messrs. Fleischmann and Pons. The experiments involve encircling a thin rod of palladium metal with a wire of platinum and plunging the two electrodes into "heavy" water in which the hydrogen atoms are a doubly heavy form known as deuterium. When an electric current is applied to the palladium and platinum electrodes, the heavy water did begin to break up, or dissociate. Ordinarily the electrolysis, or breakup, of the water would consume almost all of the electrical energy. But Messrs. Fleischmann and Pons said their experiments also produced large amounts of heat. The heat energy plus the energy consumed by the breakup of the water molecules added to far more energy coming out of the apparatus than electrical energy going in, they reported. Because they also detected tritium and indications of nuclear radiation, they asserted that the "excess" heat energy must be coming from energy released by the nuclear fusion of deuterium atoms inside the palladium rod.

As of last weekend, a dozen labs also have reported measuring "excess" heat from similar electrolytic experiments, although amounts of such heat vary widely. One of the seven reports presented here of excess heat production was given by Richard A. Oriani, professor of chemical engineering at the University of Minnesota.

Mr. Oriani said his skepticism of the Utah claims was initially confirmed when his first experiments last spring failed to produce results. But he then borrowed a palladium rod from chemists at Texas A&M who said they were getting excess heat. "The results were fascinating," he said. On the fourth "run" with the borrowed rod, the experiment began producing excess heat. The experiment was stopped briefly to change an instrument. When it was restarted, heat output "really took off" and produced excess heat for several hours before dying down, he said.

Typical of other experiments, Mr. Oriani said his experiment was "very erratic." It would go along doing nothing but dissociating the heavy water and then at totally unpredictable times, it would begin producing excess heat for as long as 10 or 11 hours before quieting down. The excess heat was 15% to 20% more than the energy involved in the electrolysis of water.

Mr. Oriani said the heat bursts were too large and too long to be explained by the sudden release of energy that might have slowly accumulated during the experiments' quiescent times, as some scientists have suggested. "There is a reality to the excess energy," he said.

Other scientists said they also were getting sporadic bursts of excess heat lasting several hours at a time. The bursts often occur, they said, after they "perturbed" the experiments by raising or lowering the amount of electric current being applied, or switching the current off and on. One chemist privately suggested this hinted that some "anomalous" chemical reactions might be producing the heat.

One reason questions surround the heat experiments is that they involve unusually meticulous measurements. Typically, the input energy ranges from a third of a watt to one watt and the excess energy is measured in tenths of a watt. One exception is a continuing experiment at Stanford Uni-

Please Turn to Page B5, Column 1

Firms Challenge
rip on HDTV

Machines Corp., which is collaborating with Toshiba on computer displays, they are poorly positioned to exploit advances in large panels. General Electric Co. recently sold off its interests in liquid-crystal displays to Thompson-CSF of France. "We found the market not developing as we thought it would," a GE spokesman says.

The small U.S. firms are persisting because of their strong positions in patents, and because the prize is still there to be seized. "No one yet has shown the ability to manufacture these panels" at commercial costs, says Zvi Yaniv, the president of Ovonic Imaging. He says he thinks his company is just a few years from doing

New Developments in Cold Fusion Give Cold Comfort to Scientists

Continued From Page B1

versity where as much as 10 watts of energy are being put into the electrolytic cells. A cell filled with heavy water is producing 1.0 to 1.5 watts more heat than an identical electrolytic cell filled with ordinary water next to it, reported Turgut M. Gur, an associate of materials scientist Robert A. Huggins, head of the Stanford experimental team.

One of the few hints the excess heat might be produced by fusion came from brief remarks by chemist John Bockris of Texas A&M University. Mr. Bockris previously reported getting bursts of excess heat and of detecting increasing amounts of tritium forming in the heavy water. He said that within the past few days, he's gotten evidence that there is a "weak correlation" between the time the heat bursts occur and the production of tritium. There isn't any way to continuously measure the amount of tritium in the heavy water, so it's been difficult to tell whether the tritium formation is related to the heat bursts or some other phenomenon.

Increasingly careful attempts to measure neutrons, which would be strong evidence of fusion reactions, continue to be negative. Messrs. Fleischmann and Pons initially reported indirect evidence of neutrons being produced in their experiment but later conceded the measurements were questionable. Researchers at Sandia National Laboratories in Albuquerque, N.M., reported they went so far as to take a "cold fusion" experiment and three neutron detectors into a tunnel under 300 feet of granite to shield the detectors from cosmic rays. A number of times they detected neutrons in one, sometimes two, of the three detectors, but only once during 411 hours of the experiment did they detect a neutron burst in all three detectors—and they think that was a spurious event.

Shimson Gottesfeld of Los Alamos National Laboratory said researchers there detected a burst of neutrons from an early cold fusion experiment last April but decided not to announce it until they could confirm it. In subsequent experiments, one of two neutron detectors occasionally indicated a burst of neutrons but neutron bursts were never recorded in both detectors at the same time. They concluded the indications of neutrons stemmed from faults in the detectors rather than from the cold fusion experiment.

At the Lawrence Berkeley Laboratory in California, new experiments indicated that the lithium added to the heavy water so it will conduct a current can produce previously unsuspected electrical effects on the surface of the palladium rod—which Messrs. Fleischmann and Pons might have misinterpreted, reported Philip Ross from the California laboratory.

WHO'S NEWS

Manhattan National
T ay to Head
Units

A. SCHULMAN Inc. (Akron, Ohio)—Terry L. Haines, formerly general manager of Canadian operations, was electe to the new position of vice president, Nor American sales, of this plastics conce Also, Larry A. Kushkin, executive v president, North American operatio named head of the

Richard L. Garwin
IBM Research Division
Thomas J. Watson Research Center
P.O. Box 218
Yorktown Heights, NY 10598
(914) 945-2555

October 24, 1989
(Via FAX to 9-(512) 471-0088)

Professor Allen J. Bard
Department of Chemistry
College of Natural Science
University of Texas at Austin
Austin, TX 78712-1167

Dear Allen,

Thanks very much for your FAX of 10/19/89 with the brief report of the NSF/EPRI Workshop. More and more bizarre results!

My purpose in writing, though, is to comment on the Mahajan paper that you sent me by FAX 10/23/89. I believe that there is a serious error in the paper that vitiates its result, and I would be grateful if you would bring it to the attention of the authors. If the cross section for the inverse process gamma + He is indeed calculated as stated, it throws out the baby with the bath water.

On page 2 of the manuscript, the authors indicate "The cross-section ... was calculated by Flowers and Mandl using Gaussian-nuclei, and free-particle wave functions to represent their relative motion." Under these assumptions, only phase space comes in to the calculation of the cross section, aside from the overlap integral within the nuclear radius. However, one can certainly not use "free-particle wave functions" for deuterons below 200 keV, and as one gets increasingly closer to threshold for the inverse process, the fact that the product deuterons are not free but are moving in their mutual Coulomb potential must suppress the cross section in just such a way as to give the usual barrier penetration behavior.

If the authors would like to write me direct, I would be glad to hear from them.

Very best regards and thanks again.

Sincerely yours,

Richard L. Garwin
Forwarded in his absence

cc:
J.P. Schiffer, Argonne (Via FAX to 9-(312) 972-3903)

RLG:jtml:297%AJB:102489.AJB

Date: 24-OCT-1989 20:30:11.85
From: "SCHIFFER@ANLPHY (312)972-4066 FAX:972-3903" <SCHIFFER@ANLPHY>
To: rlg2@yktvmv.BITNET
Subject: final clarifications
X-ANJE-To: GARWIN,SCHIFFER

Dear Dick,

Thanks for your helpful comments -- almost all have been incorporated. I am reluctant to add the latest BYU preprint that I received only today -- though will do so if you feel strongly.

I do not understand your reaction to the last Nature article by the Russian group. I agree that both this and their earlier work are highly suspect, but why is this any worse than many of the other questionable results (e.g. Frascati) that we do discuss?

I wrote something on 'fracto-fusion' and on the BNL work for possible inclusion -- but would like to discuss it with you. Hate to badger you further but will try to call you tomorrow morning and perhaps we can settle this in a couple of minutes.

John

III. NEUTRONS

IIId. Fracto-Fusion and Other Effects.

In 1986 a group at the Institute of Physical Chemistry in Moscow reported that when a single crystal of LiD was fractured by a device powered by an air gun, a few neutrons appeared to be produced [Klu86]. These were attributed to internal sparks associated with fractures in the material. Recently the same group reported that when titanium chips were agitated in a drum with heavy water and deuterated polypropylene, using steel balls and vibration at 50 Hz, neutrons were observed for a few minutes at a rate of 0.31 +/- 0.13 counts/sec [Der89]. After a few minutes no neutrons were seen. Neutron emission during plastic deformation of deuterium-containing solids under pressure is reported by Yaroslavskii [Yar89] from 'rheological explosions' induced by rotating the anvils of a press on a rock sample to which grains of beryllium bronze and D2O have been added. Typically, 1000 pulses are detected in a burst, interpreted by the experimenter as arising from 10**6 neutrons.

Another effect reported recently is that of Beuhler et al. [Beu89] who accelarated singly charged clusters of heavy ice, on the order of 100 molecules, to voltages up to 325 keV. They obtained some evidence of the p + T branch, and more recently of neutrons, at a rate of about 1 per 10**11 clusters.

These effects are not fully understood at present, the experiments are difficult and need to be repeated by others. If confirmed, a quantitative understanding of such effects could lead to interesting physics. However, the scale of energies in internal sparks and in the cluster acceleration experiments is still orders of magnitude higher than the one relevant to room temperature fusion.

[Klu86] V. A. Kluyev, A. G. Lipson, Yu. P. Toprorov, B. B. Deryagin, V. I. Lushchikov, A. V. Strelkov, and E. P. Shabalin, Sov. Tech. Phys. Lett. 12 55 (1987).

[Der89] B. V. Derjaguin, A. G. Lipson, V. A. Kluev, D. M. Sakov, and Yu. P. Toporov, Nature 341 492 (1989).

[Beu89] R. J. Beuhler, G. Friedlander, and L. Friedman Phys. Rev. Letts. 63 1292 (1989).

[Yar89] M.A. Yaroslavskii (Dokl. Akad. Nauk SSSR 307 369 (1989).

IIIe. Secondary Neutron Production.

IIIf. Summary.

Most of the experimental measurements of neutrons associated with cold fusion give upper limits that are vastly smaller than that consistent with observable heat production by D + D fusion. The lack of neutrons is a very serious indicator that the early optimism in this field was misplaced.

10/23/89

Schiffer draft of 10/16/89 (pages on [illegible] patent)

p 5.5 "... site. In a ~~later to~~ later collaboration at the Gran Sasso laboratory deep underground, [BER] {Il Nuovo Cimento June 1989 pp 997–1004} involving "electrolytic infusion of deuterons into titanium" cathodes, this group reports the detection of 350 ± 51 counts of 2.5 MeV neutrons, and indicates consistency with their initial results.

Another group at BYU [PIT] {preprint of 10/13/89} ~~detects~~ electrolyzed 3M LiOD on Pd cathodes and detected about 2.2 × 10^-3 ~~cts~~ counts per second ~~[illegible]~~ as compared with 1.7 × 10^-3 counts/s for light-water cells. According to the ~~plot~~ data plot, the difference is more than 6 S.D."

p 5.6 "[Abd]" is not Similar! -- electrolytic & dry fusion.

Date: 23-OCT-1989 10:45:26.37
From: "SCHIFFER@ANLPHY (312)972-4066 FAX:972-3903" <SCHIFFER@ANLPHY>
To: rlg2@yktvmv.BITNET
Subject:
X-ANJE-To: GARWIN,SCHIFFER

I left a message for Woodard and spoke to Huizenga (who wanted to call you).

Even if you do not find time to suggest specific wording would appreciate your opinion on what we should or should not say in our section on the issues I mentioned last night. My inclination is to mention the Russian and BNL work as tentatively as possible and state that it has nothing to do with cold fusion -- all in one sentence.

John H. also asked for suggested wording for the summary -- here I think the issue is how much we should hedge things (e.g. for Jones's result where Norman Ramsey tends to be more charitable than most of the rest of us).

Will look for possible messages tonight.

Date: 23-OCT-1989 07:14:15.52
From: "SCHIFFER@ANLPHY (312)972-4066 FAX:972-3903" <SCHIFFER@ANLPHY>
To: RLG2@YKTVMV.BITNET
Subject: RE: Woodard demands.
X-ANJE-To: GATEWAY::"RLG2@YKTVMV",SCHIFFER

I will talk to Woodard about a day's delay.

On the NSF workshop, I do not take any of the data seriously -- at this point it is more a matter of public relations. My inclination is to ignore it and proceed as we had planned.

I tend to be skeptical about the Russsian fracto fusion results. The Letter in Nature gives no information on how reproducible the effect is -- whether they tried it once or many times. They only say that

a) the background was 0.05 counts/sec;
b) that the effect observed was 0.31 +/- 0.13 counts/sec;
c) that the greatest effect was 0.41 +/- 0.14 counts/sec when the drum was cooled to liquid nitrogen after the vibration stopped;
d) that smaller effects of 0.14 +/- 0.02 counts were found with LiD;
e) that after 3-4 cycles of 3-min vibration the neutron rate fell to background level.
f) that control experiments gave null results;
g) the detector efficency was measured but is not quoted.

The statistics imply 10 - 20 counts, the figure shows about 30 -- does not say that it is from one run. Again, my inclination is to leave this out -- but it is more a public relations issue than a scientific one. We can be criticized for 'ignoring important positive results'. Somewhat the same goies for the BNL heavy water droplets -- I tend to be doubtful and it is not relevant to cold fusion -- but we may be criticized for omitting it.

Am inclined to leave it at that and respond to criticism if necessary,

---

Date: 22-OCT-1989 10:54:55.54
From: "SCHIFFER@ANLPHY (312)972-4066 FAX:972-3903" <SCHIFFER@ANLPHY>
To: rlg2@yktvmv.BITNET
Subject:
X-ANJE-To: GARWIN,SCHIFFER

Dear Dick,

I hesitate to badger you, but Woodard wants a disk sent tomorrow, Monday with the latest version. If I do not hear from you will send what I have, and then incorporate changes after that. If you do happen to have some changes ready -- please let me have them before then.

More or less substantive issues I see for the neutron section, on which I would appreicate an opinion (if not text) are:

a) What more to say about Menlove

b) Should we include reference to the Russian work? Note that they have published another positive result in the last Nature 341 p 492, where they claim to see neutrons from Ti chips in a 'vibromill' with D2O and deuterated polypropylene.

c) Should we include reference to the BNL water droplet acceleration?

A more general issue will be how to react, if at all, to the NSF workshop and the publicity they raised. I am told that they are planning to have a report for release about the same time as ours -- the tone is apparent from the NYT article last week.

I spoke to Gai. He feels that he is obligated to try and come up with a result jointly with Jones. Jones took the data tapes and wants to analyze them independently for two months -- Gai feels obligated to let him do this, so he does not plan to have any new data for us that he could let us include.

John

300 keV
200 D2O → 4000
70 eV/amu = 2800 × [illegible]
2×10^5 → 10^7 cal/gr.

R. Both.

OPTIONS: ACK LOG LONG NOTEBOOK *
Local options: Search RealNode

Date: 22 October 1989, 23:15:08 EDT
From: (R.L.Garwin (914) 945-2555) RLG2 at YKTVMV
IBM Fellow and Science Advisor to the Director of Research
P.O. Box 218
Yorktown Hts, NY 10598
To: SCHIFFER at ANLPHYS
Subject: Woodard demands.
Reply-To: RLG2 at YKTVMV
Reply-Bit: RLG2 at WATSON
Reply-Xin: rlg2@ibm.com

1) They can't process all disks simultaneously. We should do our work right and submit the disk 10/25/89.

2) Menlove left Friday for China. I almost reached him in his last hour, but missed. I'll try to talk with Miller on Monday. I have nothing in writing from Menlove on H2-only or on simultaneous detection in separated detectors; unless we have that, I persist in my critical assessment.

3) I have Nature 341, but the issue before that containing p. 492. I think we can include the CLAIM, but it has more to do with fracto-fusion than with cold fusion.

4) As for NSF-EPRI, that seems to me to be a counter-offensive, come-up- with anything activity. Nate Lewis was there, and I have heard fourth-hand from him. It is ridiculous to imagine doubling the 25% Pd-106 level. And I would rather believe isotope enrichment reducing Li-6 in the first micron than nuclear reactions. Mostly, I don't believe either. Remember, BARC used NaOD, not LiOD. The Bard FAX is waiting for me at the lab. I'll see it at 0630 Monday; thus far I have seen only the Dave Goodwin FAX from the NSF-EPRI meeting.

5) Let's get a more realistic schedule from Bill Woodard.

Dick Garwin

Delivered by Airborne

Energy Research Advisory Board
to the
United States Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585
(202) 586-5444

-R.L. GARWIN-
23 OCT 89 10. 00

October 20, 1989

To: Members of the Cold Fusion Panel

The enclosed material was provided to Dave Goodwin by Steven Jones, who asked that it be made available to the Panel.

BILL

William Woodard

FIRST DETECTION OF COLD FUSION NEUTRONS

S.E. Jones,* E.P. Palmer, J.B. Czirr, D.L. Decker, G.L. Jensen, J.M. Thorne, and S.F. Taylor

Departments of Physics and Chemistry
Brigham Young University
Provo, Utah 84602

and

J. Rafelski
Department of Physics
University of Arizona
Tucson, Arizona 85721

It is a great privilege to return to Erice and to attend this special workshop. I thank Professor Zichichi and the organizers of the conference for this opportunity.

During my last visit to Erice, I spoke on the subject of muon-catalyzed fusion. Research on this subject lead to our current work on what is known as "cold fusion," and much can be learned from a brief review of studies of muon-catalyzed fusion.

Quietly and without fanfare, scientific breakeven was achieved in a fusion experiment in 1982. The term "scientific breakeven" implies that the fusion energy output exceeds the input energy of the driver of the fusion reaction. In muon-catalyzed fusion, the driver of the fusion is, of course, the muon which can induce a number of fusion reactions during its lifetime. The total energy of the muon in our work is about 130 MeV, and each deuteron-triton fusion releases 17.6 MeV. Thus, to achieve "scientific breakeven" would require that the muon induce on average 130/17.6 = 7.4 fusion reactions. It must be emphasized here that scientific breakeven ignores the considerable energy which must be invested to create

---

* Corresponding author

Erice Workshop on Cold Fusion, 12 April 1989, Erice, ITALY

tory Report No. 14, University of Miami, Miami, Florida; Ostlund, H. G., private communication.

16. Bullard, F. M. *Volcanoes of the Earth,* 2nd ed., (Univ. Texas Press, Austin, 1984).
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LA-UR 89-1974 (Rev. 2)

09/28/89 date

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

p10:
5/12 samples give positive results'

B.1 H2 control

TITLE: MEASUREMENT OF NEUTRON EMISSION FROM Ti AND Pd in PRESSURIZED D_2 GAS AND D_2O ELECTROLYSIS CELLS

AUTHOR(S): H. O. Menlove, M. M. Fowler, E. Garcia,
A. Mayer, M. C. Miller, R. R. Ryan, and
S. E. Jones

SUBMITTED TO: NATURE

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Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO 836 R4
ST NO 2629 5/81

Letter to Editor of Nature

See p4.

RESPONSE TO QUERIES REGARDING “OBSERVATION OF COLD NUCLEAR FUSION IN CONDENSED MATTER“

SIR:

We welcome the opportunity to respond to Professor Moshe Gai's questions, to clarify points regarding our cold nuclear fuion research at Brigham Young University.

(1) The detection efficiency of the BYU neutron spectrometer for 2.5 MeV neutrons was determined using a Monte-Carlo calculation based on the MCNP code [1,2]. The detection efficiency depends strongly on the energy of the incident neutrons. Consequently, a ^{252}Cf source, which emits neutrons over a broad range of energies, is not sufficient to assess the detection efficiency for 2.5 MeV neutrons without extensive Monte Carlo unfolding. Instead, we are now preparing for a measurement using monoenergetic 2.5 MeV neutrons in Livermore in conjunction with a precision energy calibration of the spectrometer.

Meanwhile, we assert that the efficiency of $(1\pm0.3)\%$ determined using the MCNP code and cited in our paper is adequate to provide an estimate of the cold fusion rate for comparison with theoretical predictions and studies of geological cold fusion, both of which are at an early stage. We hope to soon arrive at the point in our experiments where greater predictability of the fusion rates will provide the need for a more precise determination of the detector efficiency which we are now carrying out.

Monte Carlo calculation shows that by placing the lithium-6 in glass plates rather than by dispersing it throughout the scintillator, we lose only $\approx 30\%$ in neutron detection efficiency. The great advantage is that the neutron-capture signal in the glass is well defined and easily distinguishable from the signals in the liquid scintillator. With 19 atom % ^{6}Li in three glass plates in our detector we derive an intrinsic detection efficiency of

IL NUOVO CIMENTO VOL. 101 A, N. 6 June Giugno 1989

Experimental Evidence of Cold Nuclear Fusion in a Measurement under the Gran Sasso Massif.

Published

A. BERTIN, M. BRUSCHI, M. CAPPONI, S. DE CASTRO
U. MARCONI, C. MORONI, M. PICCININI, N. SEMPRINI-CESARI
A. TROMBINI, A. VITALE and A. ZOCCOLI
Dipartimento di Fisica dell'Università - Bologna
Istituto Nazionale di Fisica Nucleare - Sezione di Bologna

S. E. JONES, J. B. CZIRR, G. L. JENSEN and E. P. PALMER
Department of Physics, Brigham Young University - Provo, UT 84602

A NEUTRON COINCIDENCE SPECTROMETER

Accepted, NIM

J. Bart Czirr, Bicron Corporation and Brigham Young Univ., Provo, Utah
and Gary L. Jensen, Brigham Young Univ., Provo, Utah

Letter to Editor of Nature

RESPONSE TO QUERIES REGARDING "OBSERVATION OF COLD NUCLEAR FUSION IN CONDENSED MATTER"

Submitted to Nature in June

MEASUREMENT OF NEUTRON EMISSION FROM Ti AND Pd IN PRESSURIZED D_2 GAS AND D_2O ELECTROLYSIS CELLS*

H. O. Menlove, M. M. Fowler, E. Garcia,
A. Mayer, M. C. Miller, and R. R. Ryan
Los Alamos National Laboratory
Los Alamos, NM 87545

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FIRST DETECTION OF COLD FUSION NEUTRONS

Accepted, Proc. Erice Workshop

S.E. Jones,* E.P. Palmer, J.B. Czirr, D.L. Decker, G.L. Jensen, J.M. Thorne, and S.F. Taylor

Departments of Physics and Chemistry
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J. Rafelski
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University of Arizona

COLD NUCLEAR FUSION IN CONDENSED MATTER: RECENT RESULTS AND OPEN QUESTIONS

Accepted Journal of Fusion Energy (Sante Fe WKshop)

Steven E. Jones
Brigham Young University
Provo, Utah, U.S.A. 84602

Ge-analysis
"2.5 mm"
Results
+10 -10 pg.

OBSERVATION OF NEUTRONS DURING ELECTROLYSIS OF LiOD SOLUTIONS

William G. Pitt, John N. Harb, and Cambis J. Farahmandi

Chemical Engineering Department
Brigham Young University
Provo, UT 84602

October 13, 1989

DRAFT COPY

p 3 "pressure"

p 21

p73,

COLD NUCLEAR FUSION IN CONDENSED MATTER: RECENT RESULTS AND OPEN QUESTIONS

Steven E. Jones
Brigham Young University
Provo, Utah, U.S.A. 84602

Abstract

We have observed clear signatures for neutron emission during deuteron infusion into metals, implying the occurrence of nuclear fusion in condensed matter near room temperature. The low-level cold fusion phenomenon has been demonstrated in collaborative experiments at Brigham Young University, at the Gran Sasso laboratory in Italy, and at the Los Alamos National Laboratory. We have shown that cold fusion can be induced in metals using both electrochemical and variational temperature/pressure means to generate non-equilibrium conditions. Observed average neutron emission rates are approximately 0.04 - 0.4 n°/s.

Current efforts focus on trying to understand and control the cold fusion phenomenon. In particular, we wish to understand the correlation of fusion yields with parameters such as hydrogen/metal ion ratio, pressure (induced, for example, by electrical field or gas pressure or mechanical pressure), temperature variation, hydride phase changes, and surface conditions (e.g., a palladium coating on titanium). We want to know if the fusion arises due to the close proximity of the deuterons in the lattice (piezonuclear fusion), or rather from "microscopic hot fusion" accompanying strong electric fields at propagating cracks in the hydride. The latter interpretation would imply neutron emission in bursts. Our experiments show clear evidence for emission of $\sim 10^2$ neutrons in bursts lasting $< 50\mu s$, although random neutron-singles emissions were also observed. Experiments now underway to compare the d-d, p-d, and d-t fusion rates will be important to a consistent description of the new phenomenon. Careful scrutiny of this effect could increase our understanding of heat, helium-3, and tritium production in the earth and other planets.

RECENT PROGRESS IN COLD NUCLEAR FUSION STUDIES AT BYU

J.B. Czirr, D.L. Decker, C.J. Faramandi, J.N. Harb, B.K. Harrison,
G.L. Jensen, S.E. Jones, E.P. Palmer, W.G. Pitt, S.F. Taylor,
J.M. Thorne, J.C. Wang

Departments of Physics, Chemistry and Chemical Engineering
Brigham Young University
Provo, Utah 84602

ABSTRACT

We continue to scrutinize the occurrence of neutron production in simple electrolytic cells[1,2,3] and in deuterium-filled cylinders.[3] We have also developed two electrolytic cell systems whose mass is isolated from the environment. One cell was designed to explore the effects of very high current densities; we have achieved over 200 A/cm^2.

We have developed two new neutron detector systems to enable us to study multiplicities and time evolution in neutron burst events, as well as random neutron production.

In recent experiments, we find strong evidence only for neutron production. Changes in tritium concentrations in the electrolytes have been consistent with electrolytic enhancement. No net power production ("excess heat") has yet been observed in either closed electrolytic system.

---

[1] S. Jones, E. Palmer, J. Czirr, D. Decker, G. Jensen, J. Thorne, S. Taylor, and J. Rafelski, "Observation of Cold Nuclear Fusion in Condensed Matter," *Nature* 338, 737-740 (April 27, 1989).

[2] A. Bertin, M. Bruschi, M. Capponi, S. De Castro, U. Marconi, C. Moroni, M. Piccinini, N. Semprini-Cesari, A. Trombini, A. Vitale, A. Zoccoli, S.E. Jones, J.B. Czirr, G.L. Jensen, and E.P. Palmer, "Experimental Evidence of Cold Nuclear Fusion in a Measurement under the Gran Sasso Massif," *Il Nuovo Cimento* 101A, 997-1004 (June 1989).

[3] H.O. Menlove, M.M. Fowler, E. Garcia, A. Mayer, M.C. Miller, R.R. Ryan, and S.E. Jones, "Measurement of Neutron Emission from Ti and Pd in Pressurized D_2 Gas and D_2O Electrolysis Cells," submitted to *Nature*.

IL NUOVO CIMENTO		VOL. 101 A, N. 6		Giugno 1989

Experimental Evidence of Cold Nuclear Fusion in a Measurement under the Gran Sasso Massif.

A. BERTIN, M. BRUSCHI, M. CAPPONI, S. DE CASTRO
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S. E. JONES, J. B. CZIRR, G. L. JENSEN and E. P. PALMER
Department of Physics, Brigham Young University - Provo, UT 84602

(ricevuto il 29 Aprile 1989)

Summary. — We have observed the emission of 2.5 MeV neutrons following the electrolytic infusion of deuterons into titanium electrodes. The present results were obtained by n-γ discriminating proton-recoil detectors at the Gran Sasso Laboratory. The observed neutron emission rate is comparable in size to the one recently reported by Jones and coll.

PACS 25.88 – Fusion reactions.

1. – Introduction.

In a recent experiment, Jones *et al.* (1) detected the neutrons emitted following the electrolytic infusion of deuterons into Ti (and Pd) electrodes. The 2.5 MeV neutron energy, which was measured by a sensitive spectrometer, is characteristic of the nuclear fusion reaction

$$d + d \rightarrow {}^{3}\mathrm{He} + n + 3.3\,\mathrm{MeV}. \tag{1}$$

The observation was then attributed to the catalysis of such a process, occurring

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(1) S. E. JONES, E. P. PALMER, J. B. CZIRR, D. L. DECKER, G. L. JENSEN, J. M. THORNE, S. F. TAYLOR and J. RAFELSKI: *Nature* (to be published).

Model of Sustained Load Cracking by Hydride Growth in Ti Alloys

See especially Figs. 4, 5 on -35°C effects
- S E Jones

W. J. PARDEE AND N. E. PATON

This paper presents a solution to the two-dimensional time and temperature dependent diffusion problem adjacent to a crack tip. This solution is used in addressing the problem of sustained load cracking in titanium-aluminum-hydrogen alloys. The theoretical solution presented indicates a maximum in sustained load cracking rate as a function of temperature. Experimental results confirm the presence of this maximum growth rate as a function of temperature. However, the temperature at which the maximum occurs is somewhat lower than that calculated theoretically. The importance of the result is that sustained load cracking rate in titanium alloys containing as little as 100 ppm hydrogen increases by several orders of magnitude as temperature decreases from room temperature to approximately −70 °C.

1. INTRODUCTION

DESPITE improvements in processing techniques, all commercial titanium products contain residual hydrogen which can, under certain conditions, influence their mechanical behavior. The amount of residual hydrogen is to some extent controllable by processing, but without special care is frequently in the vicinity of 100 ppm by weight. This paper discusses the circumstances under which these levels of hydrogen can affect crack growth in titanium structures. In particular, hydrogen tends to diffuse toward and concentrate at a region of large tensile stress. Depending on temperature, hydrogen concentration, time, magnitude of the stress, and solubility of hydrogen in the alloy, hydrogen may form a hydride. A consequence of hydride formation at or near the crack tip is that the hydride's vulnerability to brittle fracture degrades the mechanical properties of the structure.

Aspects of these phenomena have been treated[1-6] in several recent papers. This paper develops a mathematical model for two-dimensional time dependent hydrogen diffusion near a crack tip under plane strain. The solubility in the elastic strain field is modeled thermodynamically based on the hydride m[illegible] effect of plasticity on the solubility is discussed and estimated from empirical results on heating-cooling hysteresis[8] and from measurements of the critical resolved shear stress in single crystals. The model is then related to a crack growth rate by assuming an initial hydride nucleus in the plastic zone and that the hydride growth rate is, in an average sense, identical to the crack growth rate. The model is solved numerically and the theoretical crack growth rate is studied as a function of time, temperature, and stress intensity. The model extends earlier work[3] in two important respects: the model retains the anisotropic angular dependence, and the time dependence of the diffusion equation is retained.

A form of the diffusion equation, which is appropriate for numerical study of diffusion in an anisotropic two-dimensional stress field, is derived in Section 2. The model for hydrogen solubility in an elastoplastic strain field is developed in Section 3: this is combined in Section 4 with geometrical considerations to complete the mathematical model. Numerical results are presented and discussed in Section 5. Whenever possible without loss of clarity, mathematical derivations have been relegated to an appendix, as has the description of the numerical methods needed to solve the differential equations. For clarity and consistency, the SI units are given for each physical quantity as it is introduced, even though those units (such as m^2/s for diffusivity) may be unusual for a particular quantity.

2. DIFFUSION IN AN ANISOTROPIC TWO-DIMENSIONAL STRESS FIELD

This section includes three kinds of results basic to the work of subsequent sections and discusses their physical content and the limits of the approximations involved. The chemical potential of hydrogen in a spatially varying stress field is derived in Appendix A with emphasis on the (irreversible) thermodynamics involved. That result leads directly to a diffusion equation whose solution requires the Fourier components of the hydrogen flux vector and the hydrogen density. The second major result of the section is the statement, for homogenous plane strain, of those Fourier component expressions (derived in Appendix B). These expressions contain derivatives which become singular at the elastic-plastic transition; this leads to the third major result of this section, the introduction of a new physical concept, that of hydrogen pseudo-density, to avoid this mathematical difficulty. The pseudo-density concept results in both mathematical and conceptual simplification.

The continuum description of hydrogen migration in a stress field has its atomic basis in nonequilibrium statistical mechanics. The results needed here are obtained by introducing a local equilibrium distribution whose validity requires that the resulting thermodynamic variables (temperature, chemical potential, hydrogen density, stress) be slowly varying over a region

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Neutron Burst Detector

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A new version of the neutron coincidence detector has been designed and built at Brigham Young University. The calculated detection efficiency is 13% for the new detector (an order of magnitude higher than the original version.) The detector is designed for detection of bursts of neutrons from cold fusion experiments, to record the multiplicity and time evolution of the neutrons.

The detector consists of an 18 cm cubic lucite box viewed on opposite surfaces by two 13 cm diameter PM tubes. A plastic scintillator (10 x 10 x 17 cm) is placed in the center of the container and surrounded by eight thin Li-6 glass scintillators immersed in mineral oil. A 4-cm diameter hole is drilled in the center of the plastic scintillator to admit pressurized gas cylinders or electrolysis cells for cold fusion or other experiments.

Fig. 1

Neutrons interacting with the central plastic scintillator will provide a time-zero signal and the arrival time between all neutrons in the burst will be recorded for separations greater than 40 nsec. The neutrons will subsequently moderate in the plastic scintillator and mineral oil and then capture (with 13% probability) in one of the Li glass scintillators. The number of neutrons in the burst can then be deduced from the recorded capture events and the known efficiency.

As before, the glass-capture events are separated from the plastic scintillator events by pulse-height and pulse-shape criteria.

The figure shows the pulse-height spectrum for glass-capture events. The full width at half maximum is 36% for the summed light from all eight glass scintillators. This modest resolution in conjunction with the previously described coincidence requirement provides strong bias against the gamma ray background.

Fig. 2

Reference

"A Neutron Coincidence Spectrometer", J. Bart Czirr and Gary L. Jensen. To be published in *Nuclear Instruments and Methods* (1990).

A NEUTRON COINCIDENCE SPECTROMETER

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Abstract: We have developed a spectrometer for MeV neutrons that relies upon total energy absorption to measure neutron energy. A coincidence signal is required from the capture of thermalized neutrons in Li-6 glass scintillators incorporated in the detector body. This dual signal from a single neutron provides a powerful means of discrimination against background events arising either from gamma rays or from ambient, low-energy neutrons. The spectrometer is particularly useful in situations in which the neutron source intensity is very low.

The present spectrometer is the descendant of a neutron flux monitor reported previously.[1] In that monitor, thin Li-6 glass scintillator plates are immersed in one liter of a transparent organic moderator, such as decalin or mineral oil. Neutrons incident on the detector moderate in the liquid and then, with quite high probability, are absorbed by Li-6 in the glass, giving rise to characteristic light pulses. Matched photomultiplier tubes viewing the moderator volume from opposite ends then provide signals that can be amplified and analyzed.

With a simple change in the experimental apparatus but with much more complicated electronics, this neutron detector can be converted into a neutron energy spectrometer. The only change required in the detector itself is replacement of the inert moderator by a scintillator liquid, such as BC-505, which is also a good moderator. Neutron energy information can then be obtained from light generated in the liquid by protons from elastic collisions with neutrons as the neutrons moderate in the liquid. A large fraction of the incident energy is lost after six to ten collisions and within a few nanoseconds, so the